TRAUMA

Emergency Resuscitation
Perioperative Anesthesia
Surgical Management

VOLUME 1

edited by

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Christopher M. Grande
David B. Hoyt

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informa
healthcare

New York London

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Version Date: 20130813

International Standard Book Number-13: 978-1-4200-1526-3 (eBook - PDF)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

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This book is dedicated to the trauma victims, as well as the doctors, nurses, prehospital personnel, and other members of the trauma team who tirelessly strive to provide optimum care for their recovery.

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Foreword

From my recent perspective as the 17th surgeon general of the United States, along with my prior experiences as a trauma surgeon, combat experienced U.S. Army Special Forces medical specialist, paramedic, police officer, and registered nurse, I have witnessed numerous developments over the last three decades in the fields of trauma and critical care. Despite these significant advances, trauma remains the chief cause of death and disability of individuals between 1 and 44 years of age; hence, much work remains to be done.

Trauma is a worldwide phenomenon with profound public health implications and numerous existent challenges, including the need for an increased emphasis on accident prevention; overcoming barriers to care for the indigent, the elderly, and rural populations; and streamlining and improving disaster response effectiveness.

This two-volume book provides comprehensive coverage of all realms of modern trauma management, including the important aforementioned areas of care, which continue to impact the outcomes for these vulnerable populations.

Volume 1 focuses on initial management and is divided into sections that mirror the continuum of care, including prehospital, resuscitation suite, and perioperative management. The prehospital section includes chapters on trauma mechanisms, epidemiology, scoring and triage, and transport. The authors acknowledge that optimal management algorithms for this early phase of care can differ based on the setting (urban/rural) and the prevailing geographical, political, and financial conditions. Hospital-based components of management (e.g., primary survey, secondary survey, etc.) are meticulously reviewed, including specific chapters on the critical elements of care (e.g., airway management, fluid therapy, etc.). The perioperative section details the anesthetic and surgical priorities, but surgical technical details are minimized in favor of global management guidelines, which are important to all members of the care team. Important trauma-related conditions are also fully reviewed.

Volume 2 encompasses the critical care management of trauma and other surgical conditions. These topics are arranged in sections according to organ systems, with each chapter dedicated to a specific lesion or critical illness condition. Recent evidence-based principles are fully characterized, including the management of abdominal compartment syndrome, tight glucose control, adrenal suppression, and thromboembolism, etc. In addition, chapters covering post-traumatic stress disorder, family centered care, rehabilitation, and palliation at the end of life provide a breadth of coverage not present in other trauma books.

Chapters in both volumes are co-authored by experts from complimentary specialties, with surgeons, anesthesiologists, emergency medicine physicians, and pulmonologists involved throughout. Specialty sections are written by medical or surgical sub-specialists with extensive trauma and critical care experience. Interdisciplinary collaboration is further evident with chapters co-authored or edited by experienced nurses, pharmacists, and social workers, as well as occupational, physical, and respiratory therapists, among others.

The editors are eminently qualified and have succeeded in producing an authoritative and comprehensive book on trauma. Drs. Wilson, Grande, and Hoyt have each conducted important research and have published and lectured extensively on numerous trauma-related topics over the last two decades. They have assembled a superb table of contents and an expert array of contributors and associate editors. The editors have also insured that recommendations are evidence based where possible. Accordingly, the novice will learn in depth about the scientific basis of the guidelines provided here, and the expert will be updated on the latest thinking in trauma management.

In summary, this two-volume book is an extremely valuable contribution because of the importance of the subject, the fact that the topic has not been so comprehensively covered in one book until now, and because of the wisdom and insight of the editors.

Vice Admiral Richard Henry Carmona, MD, MPH, FACS
17th Surgeon General of the United States of America

Foreword

The modern-day management of trauma is multidisciplinary and requires teamwork. The specialists involved include emergency physicians, anesthesiologists, radiologists, surgeons, toxicologists, and critical care specialists along with paramedics, nurses, and technical staff.

Those involved in the management of trauma have a need for a comprehensive book that spans the entire spectrum of trauma management by all specialists, including prehospital, perioperative, and critical care. This two-volume book, edited by Wilson, Grande, and Hoyt, does precisely that. Along with a superbly designed table of contents, the editors have recruited a world-class group of contributors from all specialties to write the chapters. The editors are abundantly qualified to oversee a work of this magnitude in terms of academic and intellectual strength, as well as in terms of clinical expertise.

Volume 1 covers the areas of prehospital, emergency department, and perioperative management. Other important trauma-related conditions (e.g., alcohol and drug intoxication, burns, near drowning, environmental conditions) and management of unique populations of trauma patients (e.g., pediatric, geriatric, and obstetric) are also reviewed by experts in this volume. In addition to reviewing the key conditions, this volume contains clear guidelines for medical and surgical decision making in the various stages of care.

In Volume 2, the critical care management of trauma is reviewed. This volume proceeds in a logical systems-based presentation of the conditions and complications commonly encountered in a modern trauma or surgical intensive care unit. All of the evidence-based measures recommended to improve outcomes in critically ill patients are included. In addition, emerging topics such as the remote evaluation and management of trauma and critical illness are introduced.

As the only book to cover the full spectrum of trauma management, this two-volume set is strongly recommended for all students and clinically active physicians engaged in the management of trauma and surgical critical care.

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Foreword

Three decades ago, as an impressionable resident physician-in-training at the University of Washington in Seattle, I was asked to respond with the city's emergency medical services personnel on 9-1-1 emergency calls. Working out of the Harborview Emergency-Trauma Center, I soon began to recognize how the outcomes of those with severe injury are often determined, for better or for worse, in the first few minutes after injury. After accompanying hundreds of patients from the incident scene, in the back of ambulances, in the emergency centers, and in operating rooms and intensive care units, I soon learned that a continuity of optimized care must be stewarded by an integrated team of experts from many disciplines. In turn, I have always stressed that an interdependent "chain of survival/recovery" had to be created with each link being strong and solidly connected to each other. I have been fortunate to train, perform research, and provide care in all of those arenas, and thus appreciate the tremendous expertise and demands required of each team member at each and every link.

This two-volume book (edited by Wilson, Grande, and Hoyt) is, in many ways, the first book to examine that entire spectrum of trauma care. Accordingly, as an emergency medicine physician originally trained in surgical critical care and trauma fellowships to challenge sacred cows with clinical trials, and as a prehospital care trauma specialist who has since spent many a night responding to out-of-hospital 9-1-1 incidents, I am now honored to write a foreword for this book. For those of us who have come to understand the chain of care and the impact of early decision making on long-term outcomes, this book is a tremendous gift.

Volume 1 discusses many of the areas with which I am quite familiar, namely the initial treatment priorities in prehospital care, the resuscitation suite, and the perioperative period. These chapters are very current, including recent citations emphasizing the need for only a few assisted rescue breaths in conditions of severe circulatory impairment, while also minimizing initial intravascular fluid infusion in the face of internal injuries resulting from penetrating trauma. Associated conditions known to confound initial trauma care are also expertly reviewed.

Volume 2 covers the critical care management of trauma and the other emergency surgical conditions commonly encountered in modern surgical intensive care units. Recent evidence-based principles of care are provided for virtually every condition for which such data exist. In addition, there are chapters focusing on the patient's transition to recovery following the critical care period, including physical, occupational, and psychological rehabilitation. For example, it addresses screening and treatment of posttraumatic stress disorder.

Complementing the breadth of material, the chapters are co-written by experts from all of the relevant pivotal specialties, ranging from resuscitologists, emergency medicine doctors, anesthesiologists, and orthopedists to the spectrum of surgeons, intensivists, psychiatrists, and rehabilitation experts. In addition, the co-authors hail from around the globe, emphasizing the international appeal, perspective, and orientation of this extremely inclusive, contemporary book.

Finally, I should also say that the editors are exceptionally well qualified for a book of this magnitude. They are all experienced investigators, authors, and international lecturers on the many topics covered. In summary, this two-volume book should be considered as mandatory reading for every clinician actively involved in the care and management of trauma patients.

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Foreword

Physicians involved in the care of injured patients come from many different disciplines and are sometimes called "traumatologists." Emergency medical services personnel, emergency physicians, anesthesiologists, surgeons, intensivists, and hospital administrators are all concerned with a broad spectrum of trauma management. This two-volume book, edited by Wilson, Grande, and Hoyt, joins relatively few such comprehensive books on this subject and describes management of the trauma patient from a multidisciplinary standpoint, and emphasizes the anesthesiologist's physiologic perspective.

Internationally, the anesthesiologist is often the resuscitation or reanimation physician, with major responsibilities in the ambulance and in the evaluation area of hospitals, often without a specific trauma service. The table of contents reflects an international group of contributors assembled by the editors to author the chapters. The editors have ensured academic and intellectual strength and clinical expertise. They are to be commended for achieving such attention to detail in the first edition.

Dr. William C. Wilson, a trauma anesthesiologist and intensivist, is internationally recognized in the areas of trauma airway management, respiratory gas exchange, thoracic anesthesia, and monitoring. As editor-in-chief, Dr. Wilson's editorial leadership is evident in the clear organization of the book, fluency of the writing, and balance of coverage.

Dr. Christopher Grande, a clinically active trauma anesthesiologist and intensivist, is the executive director of International Trauma Care (ITACCS). He has published extensively in the area of trauma anesthesia and critical care for decades. Doctor Grande's editorial influence is evidenced by the expert international coverage of many topics.

Dr. Hoyt is a world-renowned trauma surgeon and surgical intensivist. He has been an active leader of numerous prestigious surgical trauma organizations, including past president of the American Association for the Surgery of Trauma and the Shock Society, as well as chairman of the American College of Surgeons Committee on Trauma. He is the current president of the Pan American Trauma Society. Dr. Hoyt's experience and wisdom are reflected in his careful editorial oversight of this comprehensive two-volume treatise on trauma care.

Volume 1 covers the areas of prehospital care, resuscitation, perioperative management, and associated trauma conditions. It is logically organized, covering the key conditions, and provides clear guidelines for medical and surgical decision making, including global operative considerations. However, by design, esoteric technical details of surgical procedures are omitted in favor of general management concepts and principles supported by recent literature. Other important trauma-related conditions (e.g., alcohol and drug intoxication, burns, near drowning, etc.) and management of unique populations (e.g., pediatric, geriatric, and obstetric) are also reviewed in Volume 1.

Volume 2 covers the critical care management of trauma and is a logical, systems-based presentation of the problems commonly encountered in a modern intensive care unit. This volume reviews medical conditions, the role of psychological factors, the family, rehabilitation, and ethics. In addition, emerging topics such as remote evaluation and management are introduced.

Because of the fundamental importance of the subject matter along with the editorial review, this two-volume set represents a compelling resource in the management of trauma and is highly recommended for all clinicians with primary responsibility for resuscitation and management of trauma patients.

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Preface

OVERVIEW OF BOTH VOLUMES

Trauma is the leading cause of death in the young (ages 1–44) in the United States and the chief reason for lost years of productive life among citizens living in industrialized countries. Despite the enormous importance of the subject matter, no single text has yet been published that fully covers all phases of trauma management.

The purpose of this book is to bring together in one source a description of modern clinical management principles for the care of the trauma patient. This two-volume set, *Trauma, Volume 1: Emergency Resuscitation, Perioperative Anesthesia, Surgical Management* and *Trauma, Volume 2: Critical Care*, thoroughly encompasses the entire spectrum of trauma management from the prehospital phase through critical care and rehabilitation.

A comprehensive table of contents, at the front of each volume, encapsulates the organization of the entire book (providing a macroscopic view), and also details the sections and sub-headings within each chapter (providing a microscopic view). The extensive index at the back of the book is organized to provide expeditious referral to specific pages that cover the subject matter of interest. The reader is encouraged to utilize both the very detailed table of contents and the index as needed to quickly locate topics.

Each chapter in this work incorporates important features that greatly enhance information communication and learning. The chapters are generously illustrated with figures and tables to facilitate synthesis of important concepts. In addition, key points are highlighted within the text and are summarized at the end of each chapter for quick review. Care has been taken to minimize redundancy by maximizing appropriate cross-referencing throughout. Another useful aspect of each chapter is the Eye to the Future section, which reviews emerging concepts and new research findings likely to impact clinical management.

The contributors to these volumes are both authoritative (having performed original research and authored numerous publications on their subject matter) and have extensive clinical experience. The authorship considered as a whole is truly international, with contributors from all continents. Furthermore, both civilian and military considerations are reviewed whenever relevant. The majority of chapters have multi-specialty co-authorship by experts in trauma surgery, trauma anesthesiology, emergency medicine, and numerous other medical and surgical specialties. In addition, chapters have multidisciplinary involvement by experts in physical medicine, rehabilitation, nursing, and pharmacy, among other disciplines. The scientific soundness is further insured by the multiple layers of editorial oversight; every chapter has been reviewed by at least three experts in the field (principal, associate and section editors). The high level of scientific accuracy and the reader-friendly nature of these two volumes are expected to facilitate learning in order to improve the care provided to trauma patients around the globe.

OVERVIEW OF VOLUME 1

Volume 1 is divided into five sections and begins to tell the trauma story. Section A (Preparation and Prehospital Care) provides the background knowledge and prehospital concepts required to manage trauma patients in both civilian and military settings. Section B instructs the traumatologist on what must be accomplished and accomplished quickly in the trauma resuscitation suite. Section C explores the principles of anesthetic management for trauma, including preoperative evaluation, preparation, and monitoring, along with the decision-making processes employed for selecting general or regional anesthetic techniques in trauma patients.

Section D details the perioperative anesthetic and surgical priorities for specific injuries. This section focuses on the most important areas of management in a systematic fashion, including chapters on maxillofacial, brain, penetrating neck, cardiothoracic, and cervical and thoracic vertebral spine injuries, along with abdominal, pelvic, and extremity trauma. Each organ system receives specific focus as well as discussion within the context of the overall management strategy for severely injured patients.

Section E surveys the numerous trauma-associated conditions with important time-sensitive diagnostic and management considerations. This section includes discussions on the management of intoxication due to alcohol, drugs, poisoning, and envenomations. Anaphylaxis and allergy are discussed with specific implications for the trauma patient. Burn injuries are extensively reviewed, as are cold- and heat-related injuries, near-drowning, and weapons of mass destruction. In addition, the less frequently encountered trauma demographics (e.g., pediatrics, geriatrics, obstetrics) each have their own dedicated chapters. Finally, the pitfalls in trauma management and the elements constituting the tertiary survey are fully described.

The absolute necessity to begin at the beginning when learning trauma management, including the principles of prehospital care and initial resuscitation and perioperative management concepts, makes this volume a must reference for the serious traumatologist and all others involved in this phase of the trauma story.

William C. Wilson, MD, MA
Christopher M. Grande, MD, MPH
David B. Hoyt, MD, FACS

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Acknowledgments

The editors would like to express gratitude to our families and loved ones for their unwavering support during the many years of planning and production of this book. Without their sacrifices, encouragement, and love, this two-volume book could not have been completed.

The associate editors and numerous section editors have likewise sacrificed time from their families and other professional responsibilities during their dedicated work on this important project. We cannot over express our gratitude for their contributions, or for our delight in the superb job accomplished by these gifted experts. Due to their diligence, this book has achieved a level of editorial oversight seldom found in multi-authored books.

Essential to the production of this work was the superb administrative assistance provided by Paul Hobson and Bertha Englund. Paul, in particular, must be acknowledged for his dedicated support, working weekends and late into many evenings throughout the process of chapter formatting and editing. In addition, the contributions made by Linda Kesselring, Jan Bailey, and Sereyrathana Keng during the early stages of this project were critical to the ultimate success of the book. The excellent administrative support of Linda Collins throughout the project was likewise essential.

Also vital to the development of this book has been the assistance of ITACCS (International TraumaCare), whose membership has contributed numerous chapters, and whose leadership has supported this project throughout its development.

Finally, we would like to acknowledge the expert assistance provided by our publishers at Informa Healthcare. The professionalism of this organization has been superb, starting at the top with Sandra Beberman, and throughout the publication process with the able assistance of Vanessa Sanchez and Joe Stubenrauch. The professionals at the Egerton Group (Joanne Jay and Paula Garber) were likewise essential to the production of this book. In particular, Mrs. Garber, editorial supervisor, must be commended for providing excellent attention to detail, a strong work ethic, and calm, kind leadership throughout the typesetting and final editing. Geoffrey Greenwood must also be acknowledged for helping us initiate this project many years ago. Each of these individuals has served to kindly and expertly assist our navigation through the ardors of the publication process, and we are grateful to them all.

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History of Trauma

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Those about to study medicine and the young physicians should light their torches at the fire of the Ancients.
—Rokitansky

INTRODUCTION

Since the begining of recorded time, mankind has suffered traumatic injuries including falls, burns, drowning, and injury as a result of interpersonal conflict. While the mechanisms of injury and incident rates for specific wounds may have changed over the millennia, trauma remains a significant cause of death in modern society.

The history of medical care for trauma is understandably the history of the management of military trauma, because many innovations came as a result of the management of battle casualties or the application of new medical and surgical techniques to battle wounds. An example is the invention of the "flying ambulance" by Dominique-Jean Larrey in 1792 (Fig. 1). He recognized that mortality of wounded soldiers in Napoleon's army could be improved with use of a specially designed horse-drawn wagon, which would remove the casualty quickly from the front lines to a hospital (1). It is not difficult to see how today's Medevac system bears a conceptual relationship with Larrey's idea. Likewise, the history of trauma care cannot be divorced from the history of medicine itself, so, at relevant points, those individuals that had a major impact upon the development of medicine are also discussed.

Other chapters within this book provide specific historical references to their unique areas of trauma care. For example, the history of fluid management is briefly reviewed in Volume 1, Chapter 11, and the evolution of burn management over the last century is provided in Volume 1, Chapter 34. In addition, the historical evolution in scientific and ethical considerations of the mind–brain and consciousness is briefly reviewed in Volume 2, Chapter 16. Similarly, the history of artificial ventilatory techniques and their relationship to the establishment of critical care medicine as a specific branch of medical care are reviewed in Volume 2, Chapter 69. Other historical vignettes are sprinkled throughout the book, as deemed relevant by the authors and editors. This chapter provides a broad framework of the vast evolution in trauma management that has occurred over the ages with emphasis on the most important advances, and especially those not covered elsewhere in the book.

This chapter provides a historical survey of trauma management, with particular focus on resuscitation, wound care, and use of analgesics and anesthetics from antiquity to the current era. This is accomplished by dividing the vast body of knowledge into epochs. Most epochs are highlighted by a sentinel event that changed the behavior of practitioners thereafter for a prolonged period. In this way, the million and a half years that mankind has suffered trauma and pain is covered, emphasizing the important innovations without getting bogged down in nonmedical historical details, which are of little importance to the student of medical history.

The designated epochs are somewhat arbitrary: the epoch of prehistory begins with the appearance of mankind on the earth; the early civilizations extend from 3000 B.C. to 200 A.D. including the Egyptians, Greeks, and Romans (Indian and Chinese influences are scattered in the chapter, but are not specifically addressed.) The European Dark and Middle Ages (200–1500) correspond with the development of medicine in the Middle East where earlier information is retained. The Renaissance began in the 1500s with the re-discovery of early Greco-Roman writings translated into Latin. The epoch of inhalation anesthesia begins slightly before 1800 with the discovery of nitrous oxide but, in 1846, the public demonstration of ether by Morton is often cited as the event that launched inhalation anesthesia. The discovery of antiseptic strategies began in 1848 with the work of Semmelweis, and Lister in 1867; however, these lessons were not advanced to the battlefield until World War I. The epoch of regional anesthesia begins in 1884 with the ophthalmic administration of cocaine. The epoch of intravenous (IV) anesthesia and the antibiotic era of trauma management begin in 1934 with John Lundy's report on thiopental, and Fleming's work on penicillin. The epoch of fluid therapy begins in 1950 with a paradigm shift away from dextrose water toward the use of electrolyte solutions. We have arbitrarily established the epoch of precision pain control at 1986. Lastly, we also discuss the development of the emergency medical services from rather humble beginnings to the current system, which, in some ways, resembles the efforts utilized on battlegrounds to get

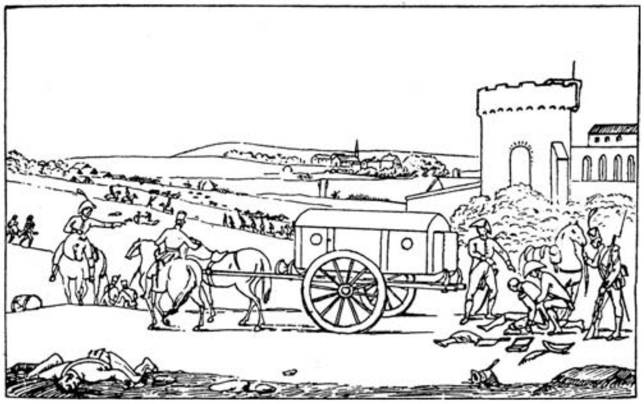

Figure 1 Larrey's "flying ambulance." Baron Dominique-Jean Larrey (1766–1842), surgeon to Napoleon, invented the flying ambulance, so that wounded soldiers could be picked up and taken away from the battlefield to receive medical attention.

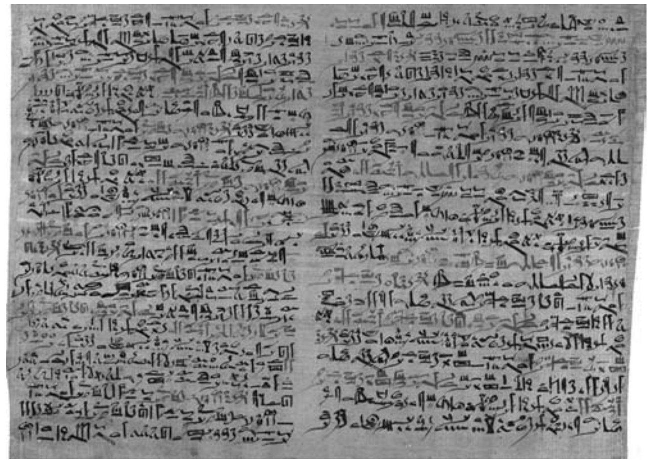

Figure 2 Edwin Smith Papyrus. Plates vi and vii of the Edwin Smith Papyrus. The papyrus describes 48 cases of injury: how to diagnose and, if possible, treat the injury. Of the 48 cases of injury described, only one has a mystical cure suggested as treatment. *Source*: Courtesy of New York Academy of Medicine.

those suffering from trauma stabilized and transported to centers of definitive treatment as quickly as possible.

PREHISTORY

One of the earliest descriptions of healing following trauma is biblical: "And the Lord God caused a deep sleep to fall upon Adam, and he slept; and He took one of his ribs, and closed up the flesh instead, thereof" (2). Since the beginning, mankind has sought to relieve the pain of wounds or disease and provide care for those who are injured. Perhaps, empathy for a fellow human who is suffering is part of our nature. Perhaps, primitive people were motivated by a fear of being left alone in pain if they themselves were injured. Whatever the motive, the effort seems to be present in diverse cultures in scattered parts of the world.

Skeletal remains of prehistoric humans show evidence of multiple healed fractures, testifying to the violent nature of prehistoric society and showing that even prehistoric society provided care for its injured members. The Stetten 1 skeletal remains from southwestern Germany, dating to the early Stone Age of approximately 34,000 years ago, show evidence of a healed lumbar spine fracture (3). This demonstrates not only that traumatic injuries occurred, but that they were not always fatal, suggesting that even the earliest human society provided supportive care to permit recovery from trauma.

The Similaun mummy (known worldwide as Oetzi) found near Hauslabjoch in the Italian Alps in 1991 dates to 3300 B.C. As well as the skeleton, soft tissue has been well preserved in glacial ice and provides compelling evidence of a violent death. A flint arrowhead was the cause of death and may well have resulted in a fatal pneumothorax. Oetzi's body is remarkable for many reasons. Not least, the presence of 57 tattoos, which correspond closely to modern acupuncture sites possibly indicating that this technique was used in Europe as well as China to treat various ailments including osteoarthritis.

EARLY CIVILIZATIONS, 3000 B.C.– 200 A.D.

Egyptians

With the advent of civilizations that utilized writing, more evidence than skeletal remains is available to determine how the ancients dealt with traumatic injury. The pre-eminent example comes from Egypt. Egypt had a high standard of medical knowledge and care for its era, even from the earliest days of the Pharaohs. Homer, writing in the Odyssey stated, "In Egypt, the men are more skilled in medicine than any of human kind" (4). The oldest known surgical treatise comes from Egypt and could be accurately characterized as a treatise to deal with traumatic injury. The Edwin Smith Papyrus (Fig. 2) was written around 1700 BC, and is an incomplete copy of an older papyrus, which has been lost to antiquity. The original papyrus dates back to the Egyptian Old Kingdom, 2600 B.C. to 2200 B.C., the era in which the great pyramids were built. It is possible that the original author was Imhotep, a physician-architect of Pharaoh Zozer in the third dynasty.

The Edwin Smith Papyrus is remarkable in that it describes 48 cases (mainly related to trauma), each of which is divided into title, examination, diagnosis, and treatment, providing detailed criteria for classifying the injury. The injuries described are almost exclusively the result of trauma, ranging from a broken upper arm to gaping head wounds with the exposure of the brain. Based upon the results of the classification of the injury, cases were put into three categories of treatment, those whose outcome was favorable, those whose outcome was uncertain, and those who could not be treated. Detailed instructions were provided for the care of injuries, even among the class of injuries that could not be treated, as it was recognized that even among those cases that could not be treated, some would survive the injury.

Among the 48 cases described in the Edwin Smith Papyrus, only one suggests cure by magical methods, with the rest having more rational treatments such as splinting of fractures. This presents a contrast with other ancient Egyptian medical documents, including the longest in length known medical papyrus, the Ebers Papyrus (Fig. 3). The Ebers Papyrus was originally purchased by Edwin Smith in Luxor in 1862, then sold to the Egyptologist George Ebers. It has a date of the ninth year of the reign of Imenhotep I (c. 1534 B.C.). However, one portion of the papyrus includes historical reference to the first dynasty (c. 3000 B.C.).

Figure 3 Eber's Papyrus. This Egyptian medical document (~1550 B.C.) provides recipes to cure diseases; many of the remedies in this papyrus are mystical in nature.

The Ebers Papyrus contains around 700 magical formulas and folk remedies for maladies ranging from dentistry to intestinal disease. This contrast illustrates that ancient Egyptians did not distinguish between the mystical and the rational in medicine, utilizing what they considered to be the best treatment available, whether by means that modern society would consider rational or mystical. The contrast also suggests that early civilizations were aware that trauma-induced injuries differed from disease, and sought practical means by which traumatic injuries could be addressed. In short, traumatic injuries were comprehensible, whereas causes and solutions for disease were mysterious. In most ancient cultures, medicine was a set of mystical processes designed to promote wellness by averting the wrath of angered gods or evil spirits.

Greeks

Ancient Greece also produced individuals who are important in the history of medicine. Hippocrates (Fig. 4) is one of the giants in the history of medicine. Born around 480 B.C., Hippocrates was trained on the island of Cos, off the coast of Asia Minor and is widely considered to be the father of medicine. Hippocrates' personal life is largely unknown, but history has preserved portions of what is known as the Hippocratic Corpus, a series of medical treatises. None of the Hippocratic Corpus can definitely be ascribed to Hippocrates himself, and scholars are generally in agreement that they are the work of several authors.

Of significance to the development of medicine as a science, however, Hippocrates postulated that diseases were not the result of angry or mischievous gods, but rather an imbalance of the four humors: blood, yellow bile, black bile, and phlegm. Humoral theory, contained in the treatise *The Nature of Man*, discusses the necessity of maintaining a balance of these humors. Humoral theory formed the basis of therapeutic treatment, in which the physician would attempt to balance the humor thought to be causing the illness. **Humoral theory or developments of humoral theory dominated medicine from the era of Hippocrates up to the time of the Renaissance.**

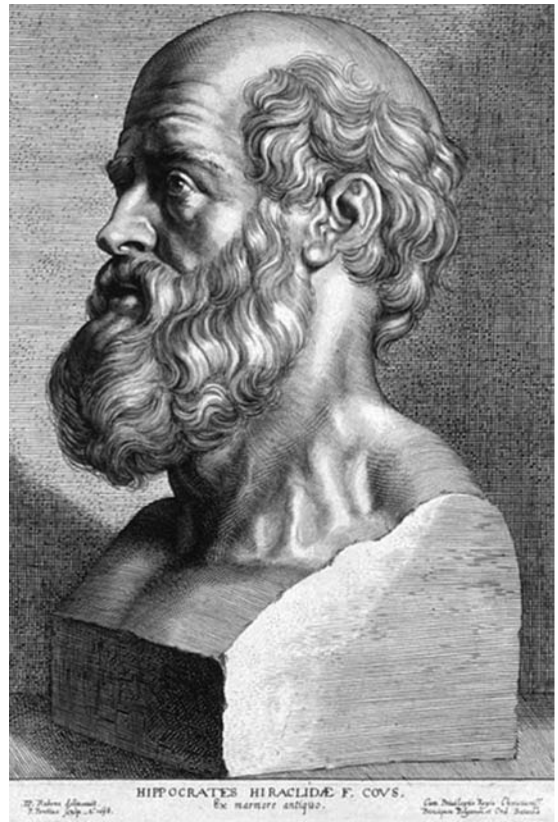

Figure 4 Bust of Hippocrates. Born on the island of Cos around 60 B.C., Hippocrates chronicled a number of aphorisms and treatments. Many writings attributed to him were originally the works of others. Hippocrates is thought to have attempted to bring rationalism to medicine, though he based his systematic approach upon the four humors.

One of the surviving texts of the Hippocratic Corpus, *On Injuries of the Head*, is a treatise on the surgical management of traumatic brain injury (TBI). A relatively recent study of this text by Maury Hanson notes the similarity in content between the Edwin Smith papyrus and *On Injuries of the Head* and relates the similarities to the interplay between ancient civilizations in the eastern Mediterranean. *On Injuries of the Head* was influential in subsequent centuries, and in the sixteenth century it was translated into no less than five languages (5).

As a result of the conquest of the civilized world in the Mediterranean and Asia by Alexander the Great, the Hellenic age arose. Among the many significant accomplishments of Alexander the Great was the establishment of Alexandria on the coast of Egypt in 331 B.C. Alexandria served as the port by which the grain of Egypt flowed throughout the Mediterranean and quickly became one of the largest cities in the ancient world. Following the death of Alexander, his heir Ptolemy founded a dynasty that ruled Alexandria until, under the terms of the will of Ptolemy in 80 B.C., Alexandria was bequeathed to Rome. Under the Ptolemic dynasty, one of the seven wonders of the ancient world, the Library of Alexandria, was founded. The Library of Alexandria became the largest repository of books in the ancient world and drew researchers and intellectuals, serving as the incubator of the advancement of knowledge in many fields, including medicine.

Figure 5 Aristotle (384–322 B.C.). Aristotle was the first to pronounce that man is an animal, and in so doing, he established a bridge between biology and medicine. Darwin called Aristotle "the world's greatest natural scientist." Aristotle's private university, the Lyceum, was a place of study for natural sciences.

Under the influence of the philosophical propositions of Aristotle, tutor of Alexander the Great, dissection of corpses became common in Alexandria. Previously, dissection was condemned on religious grounds. Aristotle (Fig. 5) held that the soul of man was a higher form than that of the physical body, which permitted the study of the body following death. As a result, knowledge of anatomy flourished, including understanding of the brain, nervous system, and circulatory system. Herophilos attempted to formulate a theory on the pulse, correctly relating pulse to heart function, as opposed to a function of arteries. Herophilos asserted that the pulse had a diagnostic value and, in the absence of the ability to accurately time the pulse, attempted to marry pulse rate and musical theory.

Erasistratos advanced the idea that the nervous system was not hollow or filled with air, but that it was solid. Erasistratos believed the nervous system was filled with "spinal marrow," but he was able to distinguish between sensory and motor nerves.

Greek mythological writings convey a knowledge of medicine and treatment of traumatic injuries that influenced Roman and subsequent medical thinking. Indeed, Homer's *Illiad* depicts a dialogue from Chiron, teacher of Achilles (Fig. 6) that reflects the sophistication of medical transport and treatment of that time: "... But save me. Take me to the ship, cut this arrow out of my leg, wash the blood from it with warm water and put the right things on it—the plants they say you have learned about from Achilles who learned them from Chiron, the best of the Centaurs."

Figure 6 Achilles tends to the wounds of Patroclus. Many depictions of Greek medicine involve battle injuries, especially of the Heroes, as in this noted vase painting.

The Romans

While Alexandria was formally bequeathed to Rome in 80 B.C., the influence of Rome on the ancient world was by then well established by both conquest and trade. Romans of the ancient world exhibited a complex mixture of practicality and superstition. In medicine, Rome's Etruscan roots of an agricultural society formed the basis of early medical treatment. Herbs and medicinal materials were often mixed with wool, a substance with which the early Roman's ascribed mystical powers. The head of the family, the *pater familias*, was in charge of the medical care of both livestock and humans under his control.

In 219 B.C., according to Pliny's *Natural History*, Rome obtained its first physician, a Greek named Arcagathus (6). Arcagathus was granted citizenship and his practice was set up at the expense of the city. Arcagathus was a surgeon, and his avid use of surgery and cautery soon dimmed his popularity among the citizens of Rome, who gave him a new cognomen. Arcagathus became known as Arcagathus Carnifex or Arcagathus the executioner. Such was Arcagathus' reception among Roman citizens that it was over 100 years before another Greek physician came to Rome.

The physician in Roman society was viewed with some degree of disdain. Contemporaneous writings from Rome illustrate this all too well. One epigram reads: "Until recently, Diaulus was a doctor; now he is an undertaker. He is still doing as an undertaker, what he used to do as a doctor" (7).

Despite a lack of public esteem, Roman surgeons were very capable, likely due to the constant need for surgical care of battle injuries (Fig. 7). In the section of the Hippocratic treatise known as *In the Surgery*, it is stated that "if a physician wishes to become a surgeon, he must go to war." Rome certainly provided ample opportunity for this type of education and, as a result, Roman surgeons were capable of dealing with numerous traumatic injuries. If a

Figure 7 Roman surgeon attends to Aeneas, who sustained an arrowhead wound in the leg during battle. Fresco from Pompeii. *Source*: Courtesy of Museo Nazionale, Naples.

fractured limb could not be reduced without surgery, a Roman surgeon could operate to reduce the fracture. While thoracic surgery was rarely attempted, Roman physicians utilized both internal and external sutures to close wounds. Trephination was performed, and Roman physicians also understood how to surgically treat depressed skull fractures. Though not fully documented, it is likely that much of this knowledge came by way of Egyptian and then Greek teachings.

Roman Aulus Cornelius Celsus lived between approximately 25 B.C. and 50 A.D. (8). Whether Celsus was a physician is a matter of some dispute; however, in his surviving treatise, *De Medicinia*, there are descriptions of many types of surgery undertaken by first century Roman physicians, including the following description of treating a depressed skull fracture:

> When the fractured bone is depressed, it need not all be excised. But whether completely broken off and separated from the rest, or still attached by a small portion to the skull around, the fragment should be separated by the chisel from the sound bone. Next, in the depressed fragment, close to the groove which we have just made, holes are to be bored as well; two when the damage is of small extent, three when larger, and the intervening partitions must be cut through. Next the chisel is to be so used on each side of the said groove, that a crescent-shaped gap is made with its convexity on the side of the fragment, and its horns directed towards the intact bone. Then if there are any detached fragments which can be easily removed, they are to be seized with forceps made for the purpose and particularly the pointed fragments which are irritating the membrane. If this cannot be done easily, the plate which I have suggested as a guard of this membrane is to be passed underneath in order that all pointed fragments which project inwards may be cut away over the plate, and any depressed bone is to be raised by means of the same plate. This method of treatment ensures that fragments still attached become consolidated; and detached fragments come away in course of time under the dressing without any pain; and by that treatment there is left a gap in the skull large enough for the extraction of matter; and the brain is better protected by leaving the bone than if it had been excised. After this, that membrane should be sprinkled with strong vinegar, in order that any bleeding from it may be checked, or any collection of clot which remains inside may be broken up. Then the same plaster, softened as described above, should be put on the membrane itself; and the rest of the dressing as before, ointment on the lint, and unscoured wool; the patient should be kept in a warm room; the wound dressed daily, even twice a day in summer (8).

This description demonstrates a sophisticated approach to a depressed skull fracture mixed with a reference to the traditional, mystical medicinal use of wool.

Two Roman physicians that had influence well beyond their lives are Dioscurides and especially Galen (Fig. 8). Dioscurides was born in what is now Turkey and served as a physician in the Roman Army, living from approximately 40 A.D. to 90 A.D. In approximately 65 A.D., he authored a text on herbal medicines called *De Materia Medica*. It was widely circulated in many civilizations, including those of Arabia. Dioscurides' text on herbal medicine (Fig. 9) is considered by some to be the most influential

Figure 8 Galen (Clarissimus Galenus, 130–200 A.D.) of Pergamon wrote more than 300 books, many on anatomy. However, he dissected only one human, and most of his direct experience was in monkeys and pigs, thus numerous errors were made.

Figure 9 Page from Vienna Dioscorides showing a typical illustration of a plant with text describing various uses.

book on the use of natural medicinal compounds in history and it was in practical use until the 1600s.

Galen was born in approximately 129 A.D. in Pergamum, a well-developed Roman city located in Asia Minor, now a part of modern day Turkey. Galen spent around 12 years studying medicine, first locally and then subsequently in Smyrna, Corinth, and Alexandria. He returned to Pergamum in 157 and became a physician at a gladiator school. In 162, Galen traveled to Rome where he established a practice and reputation as an experienced physician. His knowledge and expertise are depicted in a clinic scene or "medicatrina" (Fig. 10). Ultimately, he became a court physician to the emperor Marcus Aurelius and spent the majority of his life as a court physician to Emperors Lucius Verus, Commodus, and Septimus Severus.

While a court physician, Galen conducted experiments on live animals to study anatomy and physiology, and especially favored the use of the Barbary ape for dissection but, more commonly, used the sow due to its greater availability. It is reported that Galen employed as many as 20 scribes to write down his thoughts and observations. **Upon his death in approximately 203 A.D., subsequent work on physiology and anatomy was abandoned, largely due to the view that Galen had said everything that could be said on these areas.** Due to Galen's reliance upon animal dissection and the religious restrictions on the dissection of human corpses, many errors regarding human anatomy are contained in his writings. Furthermore, Galen would often discuss more than one species of animal structure in his teachings without clarifying to the reader which species he was referring to, further confusing anatomy and physiology. There were other errors as well, for example, Galen believed that arteries and veins were separate systems and that blood traversed the heart by invisible pores in the chambers of the heart. **It was not until Vesalius, a 16th century Flemish anatomist, that many of the anatomical errors of Galen were exposed.** Even then, Galen's reputation and influence caused resistance to the discoveries of Vesalius (discussed subsequently), and other physicians, surgeons, and scientists who documented clear errors in Galen's works subsequently struggled to advance any ideas contrary to the (almost sacred) teachings of Galen.

Figure 10 Clinic scene, or Medicatrina, from Venetian edition of Galen's works published in 1550 showing surgical procedures described by Galen—on the head, eye, leg, mouth, bladder, and genitals—still practiced in the 16th century. *Source*: Courtesy of Collection Bertarelli, Milan.

As was the case with many of the ancient physicians, Galen was also a philosopher. While not a Christian, Galen's writings show a belief in one god and that the body was the instrument of the soul. These views made Galen's writings acceptable to the Catholic Church, as well as Arab and Hebrew scholars. As a result, Galen's writings were not suppressed by any of these various factions and remained accessible to later physicians. In *On the Elements According to Hippocrates*, Galen described the humoral theory and created his own hypothesis based upon the teaching of Hippocrates. Galen felt that imbalance of the humors caused disease, so he advocated actions such as blood letting to restore balance of the humors and health. Galen is seen as one who built upon the work of Hippocrates. Due to the benign nature of his philosophical beliefs, the dominating religious and societal precepts preserved the theories of Hippocratic medicine up to the Renaissance.

DARK AND MIDDLE AGES AND MIDDLE EASTERN MEDICAL ADVANCES, 200–1500

With the decline of the Roman Empire and the Catholic Church's perceived need to suppress both science and heresy, medical and scientific discovery was stagnated

in western Europe for hundreds of years. One example of how the suppression of heresy impacted the development of medicine can be found in the rise of importance to medicine in the city of Gundishapur, in the present day Iran.

The city of Gundishapur was founded in 271 A.D. by King Shapur I of the Sassanid empire, the third Persian empire, following a victory over a Roman army led by Emperor Valerian. In 489 A.D., members of the Nestorian faith, which was viewed as a heretical sect by the Catholic Church, were forced to leave Edessa by the edict of Emperor Zeno and Bishop Cyrus, closing down the Nestorian School of the Persians. While the religious portion of the School of the Persians relocated to another city, the secular aspects of the school relocated to Gundishapur. Under the most celebrated of Sassanid rulers, Khosrau I, who reigned between 531 A.D. and 579 A.D., Gundishapur became known as a center of science, education, and medicine, welcoming refugees from the Byzantine Empire. Khosrau I commissioned the translation of scientific texts into the local language and also invited Indian and Chinese scholars to come to Gundishapur.

The resulting Academy of Gundishapur brought important changes to the education of physicians. Instead of a prospective physician apprenticing to a single practitioner to learn medicine, those attending the Academy of Gundishapur were trained in the hospital under the tutelage of the entire faculty of the Academy. **According to an Arab text, *Tarikh al-hikama*, students were required to pass exams before they could be accredited as Academy physicians. Thus, the Academy of Gundishapur was the first teaching hospital.** Cyril Elgood, in *A Medical History of Persia* states that the credit for the whole hospital system, to a large extent, goes to the Academy of Gundishapur (9).

The Sassanid Empire was conquered in 638 A.D. by Arabs under the lead of Umar, the second Caliph of Islam. The Academy of Gundishapur persisted for hundreds of years but, in 832 A.D., Caliph Al-Ma'mun established the House of Wisdom in Baghdad. The House of Wisdom was modeled upon the Academy of Gundishapur and staffed with graduates of the Academy.

One of the great Arab physicians, Al-Razi, spent several years in Baghdad as the Chief Director of a hospital within the city. Al-Razi, born in 865 A.D., came to Baghdad from the city of Rayy, which was located near the modern day Teheran, and it is thought that the majority of Al-Razi's work was performed in Rayy. It was while Al-Razi was resident in Baghdad, however, that he recorded the first known description of smallpox. **Al-Razi distinguished smallpox from measles and wrote a book on the subject, which demonstrated the differences in the treatment for each disease.** Al-Razi's monograph on smallpox was included in a posthumous collection of Al-Razi's working notebooks called *The Virtuous Life.* This work was translated into Latin in 1279 by the Sicilian physician and translator Faraj ben Salim under the employment of Charles of Anjou and was influential in Europe specifically with regard to smallpox.

Al-Razi was possibly the first Persian physician to write a home medical manual (Fig. 11), which provided the means by which the ordinary person could consult for the treatment of common ailments, such as headache, in the absence of a physician. Al-Razi also wrote of his doubts regarding many of the theories purported by Galen, particularly Galen's humoral theory. Such was the stature of Galen that Al-Razi came under considerable criticism for questioning these paradigms, which he addressed (10).

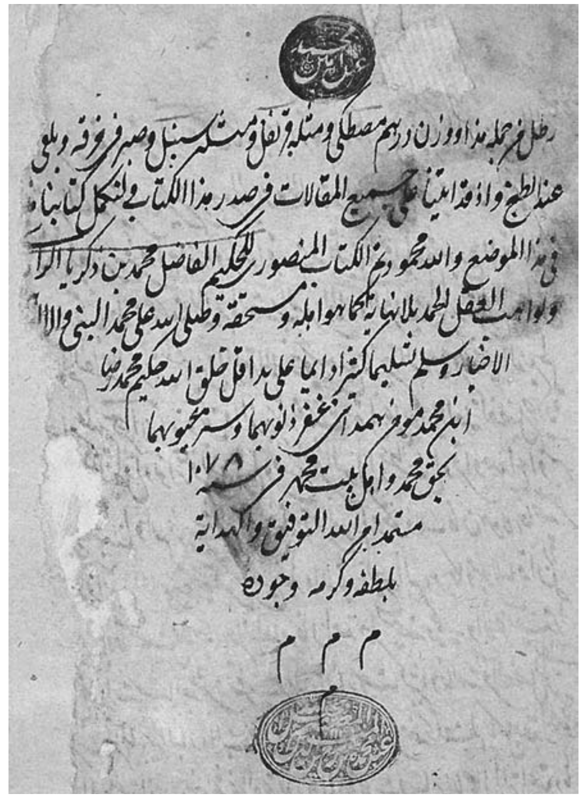

Figure 11 Al-Razi Colophone. Colophon of Al-Razi's *Book of Medicine.*

> It grieves me to oppose and criticize the man Galen from whose sea of knowledge I have drawn much. Indeed, he is the Master and I am the disciple. Although this reverence and appreciation will and should not prevent me from doubting, as I did, what is erroneous in his theories. I imagine and feel deeply in my heart that Galen has chosen me to undertake this task, and if he were alive, he would have congratulated me on what I am doing. I say this because Galen's aim was to seek and find the truth and bring light out of darkness. I wish indeed he were alive to read what I have published.

A second great Middle Eastern physician from this era was the Arab named Abu Ali Sina, more widely known by his Latinized name Avicenna. Avicenna was born in the present day Uzbekistan in 980 A.D. and died in 1037 at Hamadan, in present day Iran. While Avicenna's adult life was often chaotic due to the political instability in the various regions he resided, he was a prolific author, writing around four hundred and fifty books on a variety of subjects. Avicenna was a very intelligent man, having memorized the Koran by age 10, struggled with Aristotle's metaphysics in his early teens and eventually understanding it. At age 16, Avicenna turned to the study of medicine, achieving the status of a physician at age 18.

Avicenna's seminal book, *The Canon of Medicine*, is considered the most famous medical text of the era and was utilized by physicians for centuries, and was employed as a textbook at the universities of Leuven and

Montpellier until around 1650 A.D. *The Canon of Medicine* is based upon the work of Galen with modifications, and further information from Avicenna's understanding of medicine. In *The Canon of Medicine*, Avicenna encapsulated the sum of current knowledge of medicine available to him at the time. Among the topics covered was the appropriate use of over 700 medications, the treatment of cancer, and the contagious nature and vectors of transmission of tuberculosis. Avicenna considered medicine to be the study of the human body in health and illness, with the role of the physician to determine the means by which health in a patient has been lost and how to restore it to that patient.

The death of Avicenna roughly coincided with the start of what historians call the High Middle Ages in Europe, a period that lasted approximately 300 years. From around 1000 A.D., the majority of barbarian invasions of Europe ceased. This permitted the resettlement of lands north of the Alps as well as lands east of the traditional border of the Frankish Empire. One result of these developments was a rapid increase of the population of Europe. The European population rose to levels that would not be duplicated until the 19th century. Within 50 years of Avicenna's death, Pope Urban II called for what would be the first of many Crusades to expel Muslim rulers from the Holy Lands. While the Crusades were a new development, Christians and Muslims had been warring over the Iberian Peninsula since the conquest of most of the peninsula in 714 A.D. by the Moors.

The most famous Arabic physician of Jewish background was Maimonides (Moses ben Maimon, 1135–1204) (Fig. 12). Born in Cordoba, Spain, he fled in 1160 with other Jews to Fez in Morocco. He later migrated to Palestine and then to Cairo, where financial needs prompted him to enter medicine as a career. He rose rapidly, finally becoming physician to the sultan Saladin.

Maimonides wrote several books on medicine. His writings contained sage advice on diet, hygiene, first aid, poisons, and general medical problems, but his primary focus was on philosophy. He tried to reconcile scientific reasoning and religious faith. As Maimonides was also a Jewish scholar, he was the first person to write a systemic code of all Jewish law, the "Mishneh Torah." Orthodox Jews of his time were sometimes hostile to his views, and acceptance by the Jewish intellectuals of Maimonides as a great medical and philosophical sage came only after his death.

As a result of the contact between Christian and Muslim populations, albeit often violent contact, European populations began to be reintroduced to the writings of ancient Greeks along with Arab developments independent of the work of the Greeks, as these works had survived in the Arabic world. At times, rulers that modern society would view as enlightened emerged, such as Frederick II, Holy Roman Emperor from 1220 A.D. to 1250. Frederick II had a great interest in knowledge and learning, and sponsored many scholars so that they could advance their studies. He felt that knowledge was the basis of a virtuous ruler. Other rulers also sought knowledge and commissioned the translation of works in Arabic to Latin, including medical texts such as Al-Razi's *The Virtuous Life.* **As a result of the contacts between Christian and Muslim populations and translations of texts, the ideas of the ancients began to become known again in Europe after what can only be called the suppression of these texts by the Catholic church.**

Figure 12 Maimonides. Engraved portrait of Maimonides, as he was thought to look, with his autograph in facsimile. A Jewish philosopher and physician, his writings and practices achieved renown in Muslim Spain and Egypt. *Source*: Courtesy of New York Academy of Medicine.

The twin scourges of famine and pestilence marked the end of the High Middle Age and the beginning of the Late Middle Age. As a result of events such as the Great Famine of 1315–1317 and the Black Death pandemic of 1347–1351, the population of Europe was devastated. Some estimate that the population of Europe was halved by these two events, with the Black Death causing the death of approximately one-third of the entire population of Europe. Famine and pestilence had enormous implications for society, religion, and government. There were mass peasant revolts in numerous locations. The Catholic Church endured the Papal schism of having a Pope in Rome and a rival Pope in Avignon, France, each contending to be the true leader of the church. War, such as the Hundreds Year War between France and England, was again a significant feature of Western Europe. As a result of this turmoil, the late Middle Age did not produce much advancement in either science or medicine.

RENAISSANCE ERA, 1500

In 1453, Constantinople fell to the Ottoman Empire, causing many Byzantine intellectuals to seek refuge in the west, typically in Italy. These scholars accelerated the rediscovery of ancient Greek and Roman texts that ultimately led

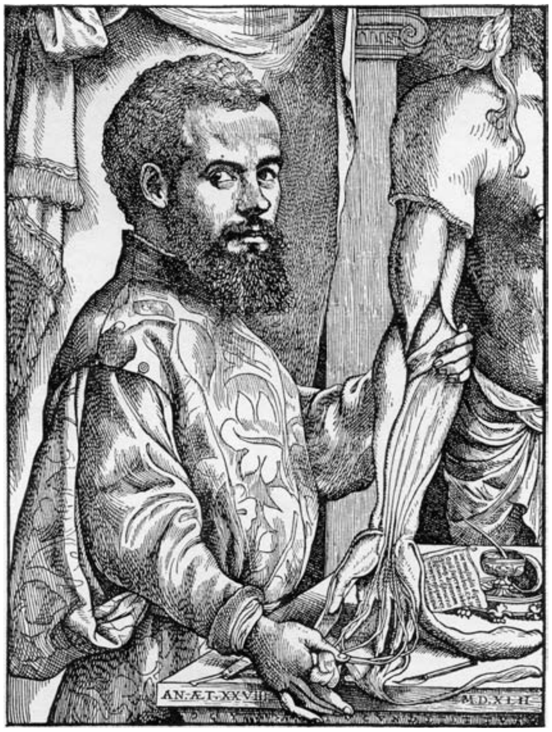

Figure 13 Vesalius. Portrait of the great anatomist Andreas Vasalius at the age of 28, from his masterpiece De Humani Corporis Fabrica (1543). *Source*: Courtesy of World Health Organization, Geneva.

to the Renaissance, which is traditionally dated to have started in 1500. With the further reintroduction of ancient texts from Byzantine sources, science and medicine flourished.

Born in 1514 to a family of physicians, Andreas Vesalius (Fig. 13) received training in both Greek and Latin prior to undertaking the study of medicine. His language skills and the emergence of classical writings gave Vesalius the tools by which he could examine the knowledge of the Greeks and Romans. Vesalius studied medicine at the University of Paris until war between the Holy Roman Empire and France forced his return to Belgium. While at the University of Paris, Vesalius studied the writings of Galen and developed an interest in anatomy. Upon graduation, he became the Chair of Surgery and Anatomy at the University of Padua.

In a break from the traditional means of teaching anatomy, Vesalius utilized dissection as the primary tool of instruction, rather than simply reading classical texts as Galen did. Furthermore, Vesalius himself performed the dissection (Fig. 14) rather than having a barber-surgeon perform it at his direction. Vesalius published a set of detailed illustrated anatomical tables in 1538, and shortly thereafter a judge in Padua became interested in Vesalius' anatomical work. The judge offered Vesalius the opportunity to dissect the corpses of executed criminals. In 1541, Vesalius discovered that Galen had based much of his research upon animal dissection, as human dissection had been banned in Rome. Soon thereafter, Vesalius began to write his own anatomical text, correcting many of the errors perpetuated by Galen.

Published in 1543, Vesalius' *De Humani Corporis Fabrica* was a illustrated text in seven volumes, which became an instant classic. Vesalius used artists to produce the drawings and had these illustrations depict anatomical structures as they would be found within the body. Because Vesalius' work directly challenged the claims of Galen, Vesalius became controversial. One of Vesalius' detractors even published an article asserting that the human body must have changed since Galen studied it. Vesalius was accused of being a mere surgeon, at the time considered to be a craftsman, rather than the more erudite physician.

At the time of Vesalius' work, the standard treatment for bullet wounds was cautery with burning oil or hot irons. Cautery was also used when limbs were amputated. The benefit of cautery was the cessation of bleeding. However, the subsequent pain and risk of secondary infection were problematic.

The history of trauma surgery in the sixteenth century is also distinguished by the work of Ambroise Paré (Fig. 15). During the Siege of Turin in 1537, Paré is rumored to have run out of burning oil to cauterize the wounds he was treating, and was forced to use a combination of ligatures to tie bleeding arteries and veins along with ointments to close the wounds. In reality, Paré had been using these techniques for years, and because Paré's patients did far better than those treated with cautery, he began to re-examine the current surgical techniques, and began publishing his findings in 1545. Furthermore, Paré found that the works of Hippocrates, Galen, Avicenna, Vaselius, among others, spoke of using ligatures to tie off bleeding vessels.

Paré also advocated using fine probes and bullet extractors to remove bullets and bullet fragments instead of amputation, as foreign body removal decreased infection. The relatively lower muzzle velocity in those days meant that bullets and shrapnel, served as bacteria-laden foreign bodies, usually needed removal—in contrast to today's standards where they are often left in place. Paré devised tools to perform bullet extractions and to extract the wide variety of arrows and crossbow bolts, which were commonly used. Paré advocated taking all possible steps to avoid amputation. Some consider Paré to be the father of modern surgery. Paré also used techniques to close facial lacerations without ligatures (Fig. 16), which decreased scar formation.

In 1575, Paré's *Ouevre* or collected works, consisting of around 1200 folio pages with over 400 illustrations, was published. Paré's *Ouevre* contains not only his thoughts, based upon a lifetime of experience in the treatment of battle wounds, but also his views on anatomy, pharmacology, obstetrics, and even mythical monsters. Reflecting the gulf between physicians and surgeons, Paré's work was published in French, not in the intellectual Latin.

In 1628, English physician William Harvey published *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus* (An Anatomical Exercise on the Motion of the Heart and Blood in Animals). **In Western society, Harvey received credit for discovering that the heart pumps blood through the circulatory system.** However, in 1924, an Egyptian physician discovered a commentary on Avicenna in the Prussian State Library written by ibn Al-Nafis, which described the pulmonary circulation. Ibn Al-Nafis was a 13th century physician from Damascus, which leads some to suggest that Harvey's publication was not the first on circulation.

Regardless of whether Harvey is properly credited with correctly describing circulation, the effect of Harvey's

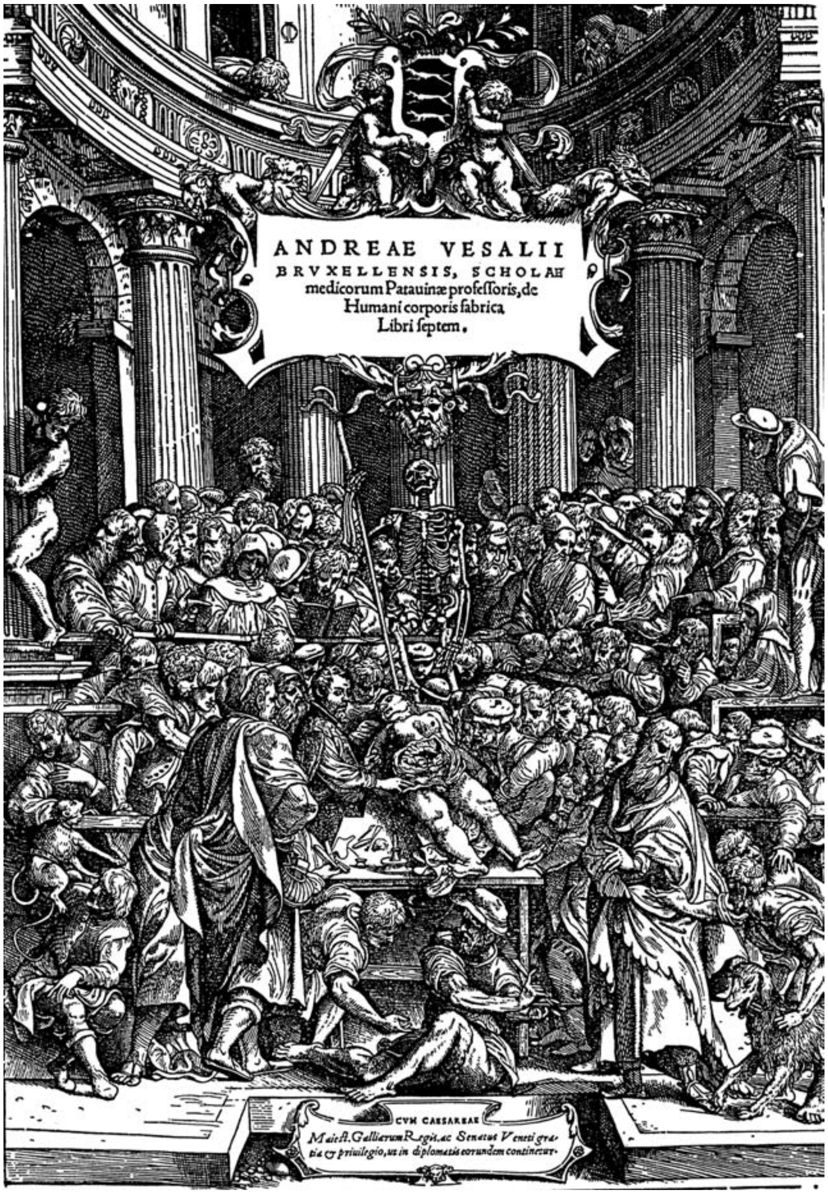

Figure 14 "Vesalius De Fabrica." Title page of Vesalius' 1543 edition of De Humani Corporis Fabrica showing Vesalius conducting a dissection on a woman before an audience of medical students and others.

publication was immediate. Harvey's description contradicted the writings of Galen, who suggested that venous and arterial blood had separate circulation, with arterial blood coming from the heart and venous blood coming from the liver. As was the case with others who contradicted Galen, Harvey's publication and ideas were attacked. However, Harvey's ideas on circulation were eventually accepted during his lifetime. However, despite the acceptance of Harvey's ideas on circulation, his description of circulation did not have much impact upon medicine during his lifetime. Galen's prescription of blood letting for various diseases continued to be a popular remedy.

Giovanni Alessandro Brambilla was born in 1728 and became a surgeon for the Austrian Army. Eventually, he came to have Josef II, the heir to the Austrian Empire, as a patient. Brambilla utilized his influence with Josef II to establish an academy where surgeons were taught both Latin and anatomy. Knowledge of Latin was necessary so that surgeons could read the intellectual works of physicians. As a result of Brambilla's efforts, surgeons in the Austrian Empire found themselves to be on a somewhat equal footing with physicians.

Also born in 1728 was John Hunter, a Scottish surgeon and physician. Hunter strongly advocated the use of scientific experimentation to advance knowledge in medicine. Hunter is famed for his aphorism, "Don't think, try the experiment," which encapsulates Hunter's approach to advancing scientific and medical knowledge. Experimentation was not an end itself to Hunter, who sought to seek practical applications for principles derived from experimentation.

Born in 1766, Dominque Jean Larrey became the surgeon-in-chief for Napoleon's army from 1797 to the battle of Waterloo in 1815 where he was captured by the Prussians. **Larrey's most famous innovation was the aforementioned flying ambulance (Fig. 1), but he was, in his own right a talented physician and surgeon.** For example, Larrey is credited with the first successful amputation of a

Figure 15 Paré portrait. Woodcut portrait of Ambroise Paré at age 68 who, without academic training, revolutionized the treatment of battle wounds and wrote the innovative treatise *A Universal Surgery* (1561). *Source*: Courtesy of New York Academy of Medicine.

leg at the hip. His fame as a physician played a role in the Prussian's pardoning Larrey from a sentence of death. Napoleon praised Larrey as "the worthiest man I ever met..." The flying ambulance innovation permitted French doctors to treat injured soldiers on a timelier basis, which improved the patient's prospects. Larrey developed a "24-hour principle," which held that amputations should be performed within a day of the trauma causing the need for amputation, noting that delay of amputation often resulted in death. Larrey wrote that prior to the flying ambulance innovation, multiple amputation was rare as the delay in performing the needed operation resulted in the patient's death.

In 1767, the Dutch Society for Recovery of Drowned Persons was established. The Society came to recommend warming the victim, removal of aspirated or swallowed water by positioning the victim's head below the feet with manual pressure on the abdomen and inducement of vomiting, stimulating the victim, forcing air into the lungs with bellows and blood letting. Prior to the formation of this Society, near-drowning was largely considered impossible to treat.

In 1774, the Royal Humane Society of England was formed under the leadership of Dr. William Hawes (1736–1808) who convinced Londoners that persons who appeared dead (but not in full arrest) following water emersion could be resuscitated (Fig. 17), along the lines established by the Dutch experience (described preceedingly), as long as emersion time was not prolonged.

In 1788, the British Royal Society awarded a silver medal to Charles Kite who wrote *An Essay on the Recovery of the Apparently Dead*, which describes the first successful defibrillation, performed on a three-year-old child who had fallen out of a second story window.

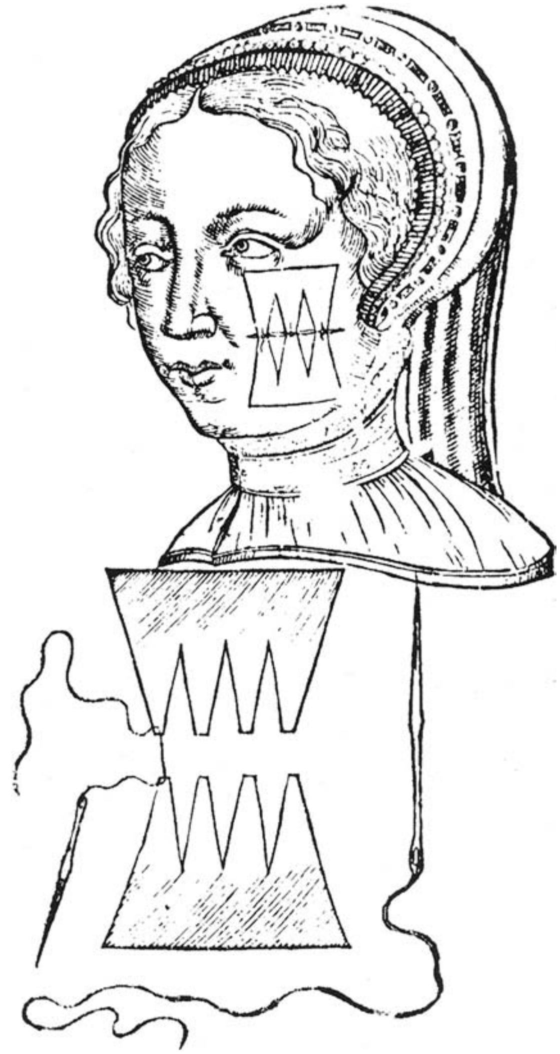

Figure 16 Paré stiched adhesive. Illustration from the *Ten Books of Surgery* by Ambroise Paré—proper technique for suturing facial wounds.

Figure 17 Royal Humane Society. Rescue of person drowning in River Thames by members of Royal Humane Society. *Source*: Courtesy of Royal Humane Society, London.

HISTORY OF ANALGESIA THROUGH ANTIQUITY (THROUGH THE 1700s)

Most ancient attempts to relieve pain consisted of surface applications of plants or organic material. For example, a Babylonian clay tablet ca 2250 B.C., recommended a cement, made by mixing henbane seed with gum mastic, for the pain of dental caries (11). The use of soporific potions taken by mouth for analgesia also goes back to remote antiquity. They were prepared from alcohol and/or plants including marijuana, poppy, hyoscyamus, and mandragora. According to the *Odyssey*, in 1149 B.C., Helen of Troy cast a drug, perhaps opium, into wine "to assuage suffering, to dispel anger, and to cause forgetfulness of ills" (12). Aurelius Cornelius Celsus describes "anodyne pills" containing poppy, the plant source of opium (13). The writers of antiquity commonly referred to poppy-induced sleep with a term used by Virgil, "letheon." Two thousand years later, "letheon" was the name given to ether anesthesia by William Morton in his greedy attempt to disguise its identity, obtain a patent, and profit from his discovery (14).

Several societies utilized pain agents in conjunction with medical treatments. In the New World, by approximately 300 B.C., Inca shamans performed trephinations in the skulls of their suffering tribesmen with the aid of a pain-relieving agent. According to the translations of their writings, they chewed the leaves of Erythroxlyn coca and spat into the wounds. The coca plant is native to South America and the plant source of cocaine, which would be expected to relieve the pain of the wound (15).

During 54–68 A.D., the Greek army surgeon, Pedanius Dioscorides, in the service of Nero, recommended the oral administration of wine with mandragora for insomnia or the pain of surgical operations and cauterizations. Several descriptions of the use of various alcoholic potions to induce analgesia exist in the writings of Dioscorides.

A ninth century recipe in the *Monte Casino Codex* called for a sponge steeped in a mixture of opium, hyoscyamus, mulberry juice, lettuce, hemlock, mandragora, and ivy. This somniferous sponge was used in minor operations in 1200 A.D. in Italy as described by the Hugh Of Lucca. To revive the patient, a sponge filled with vinegar was placed under the nostrils (16).

Mandragora was the first known anesthetic mentioned in an English book, printed by William Bullein in 1562. Mandragora contains alkaloids of the belladonna group, which explains its effectiveness as an anesthetic. Two years later, Ambroise Paré of France obtained local anesthesia by compression of nerves. In the 16th and 17th centuries, amputations became common, and the drunken state induced by brandy was frequently used to induce senselessness. Freezing mixtures of snow and ice were packed around a limb until numbness permitted an almost pain-free amputation by Marco Aurelio Severino of Italy in 1646 (17).

The concept of mesmerism and the nonpharmacological methods of anesthesia must be mentioned. Franz Anton Mesmer left a profound mark on the history of pain relief with the development of the theory of "vitalism," a revamping of the doctrine of the "power of divine touch," for the prevention of human suffering. Many cases of surgery, such as amputations, in which the mesmerized patient did not feel pain were reported. In spite of anecdotal reports of success, mainstream medicine has always considered mesmerism to be a medical curiosity (18).

Seishu Hanaoka (1760–1835) was a Japanese surgeon who genuinely believed that he had a duty to relieve his patients' pain (19). The sincerity of his compassion has earned him the title of "Angel of Medicine" in Japan. He created a mixture of herbs aimed at inducing an unconscious state in which surgery could be performed painlessly. The principal ingredients of his mixture were crushed seeds of the morning glory plant, a rich source of hyoscyamine. He called his mixture "tsusensan." Legend states that he would not try it on a patient until he had first experimented with a volunteer. Both his wife and his mother volunteered to be the subject of his first trial. His diary reflects that he struggled for several days, but finally decided to try the experiment on his wife, because she could be replaced whereas a man has only one mother. He used the mixture for painless removal of a breast cancer in 1805 and subsequently in many operations, including some for traumatic injuries. The Japanese Society of Anesthesiologists adopted the morning glory as their logo in honor of Dr. Hanaoka.

Most doctors despaired at the search for a safe way to relieve the pain of injury or the necessary surgical correction. Many believed that pain was a necessary part of surgery and definitely God's will. To try to conquer it was to go against God's will. Some surgeons even felt that the pain was necessary to prevent collapse. In fact, they attributed deaths occurring during surgery to "pusillanimity" or extreme cowardice.

EPOCH OF INHALATION ANESTHESIA, 1800

The discovery and application of anesthesia has been called the single most important contribution of American medicine to mankind. Who should be credited as the discoverer of anesthesia is a controversial subject. Most scholars acknowledge that the sentinel event was the public demonstration of ether anesthesia in the amphitheater of the Massachusetts General Hospital on October 16, 1846, by William Thomas Green Morton. While a sentinel event, it was the culmination of advances made by several individuals experimenting with two agents, nitrous oxide and ether.

In 1275, Raymundus Lullius of Spain made the discovery of ether, which was then called "sweet vitriol." In 1540, Paracelsus synthesized "sulfuric ether" by heating sulfuric acid mixed with ethyl alcohol. He observed the hypnotic properties of ether by mixing the substance with grain. When chickens were fed the mixture, they fell asleep and experienced no pain. About the same time, Valerius Cordus in Germany also synthesized ether. Ether became more than a chemical curiosity. It was widely used as a cleaning agent and solvent.

Joseph Priestly discovered oxygen in 1771 and nitrous oxide in 1772. A scientific foundation for inhalation anesthesia was laid when an English scientist, Sir Humphrey Davy, in 1798 discovered the analgesic and exhilarating effects of nitrous oxide. He also noticed that the easiest way to administer drugs was through the lungs. In 1799, nitrous oxide was introduced into medical practice at Beddoes' Pneumatic Institute primarily for the treatment of tuberculosis and other pulmonary diseases. In Sir Davy's book, *Researches Chemical and Philosophical*, published in 1800, he describes inhaling nitrous oxide himself and experiencing relief of a painful condition. He suggested that the substance might be used to reduce the pain of surgery (20). William Allen, a lecturer at Guy's Hospital in England, around 1800, demonstrated the results of inhalation of nitrous oxide, noting particularly the loss of sensitivity to pain.

During the first quarter of the nineteenth century, ether and nitrous oxide were both widely used for recreational purposes. The public was invited to sample the effects during educational lectures on chemistry. In 1844, Horace Wells, a dentist, attended one of these lectures put on by Quincy Coulton, a chemist and medical student from New York. Wells observed a man who was intoxicated by the gas injured his leg but felt no pain and had no memory of the injury afterward. On the following day, Wells had Coulton administer the gas to him while a colleague extracted a tooth painlessly. Wells began to offer painless extractions in his dental practice free of charge.

His fertile mind gave rise to the innovative concept that a drug could be inhaled, though in increasingly dangerous doses, to achieve an unconscious state during which surgical procedures could be performed without pain. His effort to demonstrate surgical anesthesia with nitrous oxide at the Massachusetts General Hospital in 1844 was considered a failure, because the patient cried out during the surgery although he remembered nothing about it later. The students and surgeons in attendance on that day called Wells' concept "humbug." He spent the remainder of his life in morose depression, finally becoming a chloroform addict and committing suicide in a New York jail where he landed after throwing acid on a prostitute in a drunken rage (21).

The first public demonstration of ether anesthesia was made before an assembled group of the faculty and students of Harvard Medical School by Morton, a medical student and dentist, who learned the concept from Wells, his partner in dental practice. Morton learned of a more powerful agent, sulfuric ether, from a professor of chemistry at Harvard, Charles Jackson. Morton put the concept and the agent together for a successful demonstration (Fig. 18) (22). Morton made the first public demonstration, but he was not the first to give ether: that distinction goes to Crawford Long of Georgia on March 30, 1842. His diary gives detailed descriptions of the patients whom he anesthetized including his wife for the birth of one of their children. Unfortunately, he did not make his findings public until six years later when the U.S. Congress offered a prize to the discoverer of anesthesia. By this time, ether anesthesia was being used around the world. Nevertheless, March 30th is remembered in the United States as Doctors' Day, a day to honor all medical doctors (23). Shortly after Morton's demonstration, on December 19, 1846, a tooth extraction was done under ether in London, followed by its use by Listran at the University College Hospital. The fame of ether spread rapidly from Edinburgh to Paris. Sir J. Y. Simpson, on January 19, 1847, used ether to relieve pain of childbirth. In the next three months, ether revolutionized surgical practice in Great Britain.

Around this time, others discovered that inhaled vapors other than ether could also be utilized to provide anesthesia. Chloroform was discovered in July 1831 by Guthrie, followed by Liebig in November 1831 and Soubeiran in January 1832, but Jean Baptiste Dumas of France defined the physical and chemical properties of chloroform in 1835. In 1838, Dr. Formby of Liverpool first used chloroform as a soothing antispasmodic. In 1842, Dr. Mortimer Glover, a young Edinburgh graduate discovered that chloroform was a powerful anesthetic and that one of chloroform's effects was to cause insensibility.

Figure 18 First successful anesthesia. Painting (1882) by Robert Hinckley. Morton, a medical student and dentist, was the first to successfully demonstrate publicly the use of surgical anesthesia on October 16, 1846, at the Massachusetts General Hospital. *Source*: Courtesy of Francis A. Countway Library of Medicine, Boston Medical Library, Cambridge.

In 1847, Simpson used chloroform on patients and later published "*Remarks on the Super-Induction of Anesthesia in Natural and Morbid Parturition with Cases Illustrative of the Use and Effects of Chloroform in Obstetric Patients*." Four days after its publication, the first death under chloroform anesthesia took place near Newcastle, England. Hannah Greener, a healthy 15-year-old, succumbed to chloroform on January 28, 1847, during a procedure to remove an ingrown toenail (22).

The Mexican War of 1845

Surgery has always been a major problem in wartime. The Mexican War of 1845 to 1848 was already underway when Morton demonstrated ether anesthesia in Boston. Casualties in the war were numerous, and amputations were considered the best treatment option for many extremity wounds. Military surgeons, who performed these operations on their screaming comrades, urged their superiors to permit the use of ether, but medical conservatism prevailed. Dr. Thomas Lawson, Surgeon General of the army during the Mexican War, responded to the physician's urgings by stating, "The new substance is ill adapted to the rough usage of the battlefield."

The war with Mexico marked the first use of anesthesia for combat casualties (24). The news about anesthesia reached a semiretired surgeon named Edward H. Barton in New Orleans. He received instruction from Morton and reported for duty in the army. He accompanied the American troops who landed at Vera Cruz in March 1847. According to Aldrete (24),

> In the process of disembarking, a German porter recently recruited was accidentally shot in his legs when a musket discharged spontaneously while he was unloading a wagon. After attempts to save his legs failed, the doctors decided to amputate both.

> Despite the surgeon's skill and expediency, the porter screamed, cried and swore throughout the first amputation so the second was postponed. On the next day, March 29, Barton proceeded to administer the first anesthetic in a war. The porter slept through the entire operation without moving one muscle and woke up cheerful and without complaint at the end of it.

This result was good, but Barton's luck did not hold. He had a few deaths and concluded that anesthesia was dangerous for war casualties. He failed to perceive that ether behaved differently in the heat of Vera Cruz compared to the winter of Boston.

Aldrete reports that anesthesia was also used on Mexican casualties by Dr. Van der Linden, a bright young surgeon of Dutch descent who served in the Mexican army. There is also mention of ether anesthesia at the Battle of Cerro Gordo, near the town of Xalapa, on April 18, 1847, and Jose Matilde Sansores administered ether on June 15, 1847, in Merida, Yucatan.

Surgeon General Lawson subsequently changed his attitude and ordered the army to examine the benefits of anesthesia in military surgery. The examination of the benefits of anesthesia for military surgical applications had proponents and opponents. One opponent, Army surgeon John Porter, had an unfavorable outlook on anesthesia as he related uncontrollable hemorrhage to ether. He said, "Anesthetics poison the blood and depress the nervous system; and in consequence, hemorrhage is more apt to occur and union by adhesion is prevented." Porter's attitude contained a powerful psychosocial bias claiming that anesthetics robbed the soldier of his "manliness" by not allowing him to experience pain during surgery (25).

The American Civil War

The Civil War of 1861 to 1865 was a landmark event in U.S. history. The war not only freed the slaves and established forever the unity of the states but is also considered by many historians to be the first "modern" war. While the Civil War may be the first modern war, the practice of medicine in America was still in what Civil War Surgeon General William Hammond called the "medical middle ages," with most doctors having only two years of medical school. **Physicians at the time of the American Civil War were without the knowledge of the utility of sterile dressings, antiseptics, and antiseptic surgery.**

Wounds from bullets were the main traumatic cause of men being sent to the hospitals. Fourteen percent of these bullet wounds caused death, and 71% of bullet wounds were the cause of amputations. The primary rifle ammunition of the Civil War was Minie balls, made of soft lead about the diameter of a quarter. Minie balls would flatten upon impact. These deformed bullets would rip through organs and shatter bones. On the battlefield, the most common cause of death was hemorrhage. As blood transfusions did not exist, the blood lost was irreplaceable. Amputation of limbs struck by Minie balls was the most common surgical procedure during the Civil War.

At the beginning of the Civil War, surgeons were generally ignorant regarding anesthesia and the controversy regarding its safety in a military setting. Both Union and Confederate armies lacked doctors with expertise in giving anesthesia. A few surgeons still believed that the stress of pain during surgery was beneficial as a "stimulant," which helped to reverse shock. Romanticized tales were told of soldier's "biting the bullet" or getting rip roaring drunk prior to going under the surgeon's knife. Morphine, which was the leading painkiller of that time, was rubbed into wounds or dusted directly into them. Opium pills were also available. Both drugs deadened the pain prior to and after surgery.

By the end of the Civil War in 1865, anesthesia had been available for almost 15 years and was being extensively applied. Anesthetic agents were manufactured in the northern states or imported from the British Isles. The Union forces, which were in control of the high seas, had easy accessibility to both ether and chloroform. Confederate forces on the other hand had difficulty importing supplies past the Union naval blockade.

On the Union side, anesthetics were used in over 80,000 cases. The record of the Civil War surgeons was quite remarkable as reported in Surgeon General Hammond's "*Medical and Surgical History of the War and Rebellion*" or MSHWR. Of the 80,000 cases, the anesthetic agent was definitely known in 8900 (76% chloroform, 15% ether, and 9% mixed agents). The anesthetic mortality was low during the Civil War despite the poor battlefield conditions. There were 37 deaths from chloroform, four from ether and two from a combination. Probably the brevity of anesthetics combined with speedy surgery explains the low mortality. Chloroform was the agent of choice because of its nonflammability and speed of action. The open drop technique (Fig. 19) was the most common method of application. The sweet smelling liquid was sprinkled onto a cotton cloth over the soldier's nose, and mouth. Amputations took no more than 15 minutes, and the average duration of the anesthetic was a little over 20 minutes.

W. T. G. Morton, discoverer of ether anesthesia, served in the Union Army and received permission from the Surgeon General to provide anesthesia during the Battle of the Wilderness and the Battle of Spotsylvania, May 4–9, 1864. He wrote of anesthetizing over 400 casualties and of producing perfect anesthesia in an average time of three minutes (26).

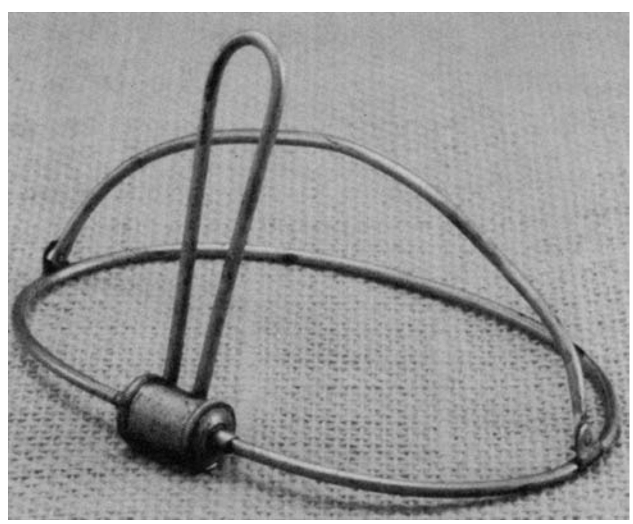

Figure 19 Open drop method. Image shows Skinner's wire frame mask. Mask is placed over patient's mouth and nose. A cloth is placed over the mask. Chloroform (or ether) is dripped onto the cloth. Patient inhales the ether and is anesthetized.

Figure 20 Civil War ambulance. Ambulance drill at headquarters, army of the Potomac near Brandy Station, March 1864.

On the Union side at the outset of the Civil War, there was marked disorganization in the treatment of battle injuries, including the evacuation of injured from the field of battle. For example, following the second Battle of Bull Run, a letter sent to the Secretary of War, Edwin Stanton, by the Surgeon General Hammond noted that a week after the end of the battle, 600 wounded were still on the battlefield in horrible condition (27).

The disorganization of the evacuation of the injured was eventually addressed by the widespread adoption of the plan generated by Surgeon Jonathan Letterman of the Union Army of the Potomac, which General McClellan ordered for the Army of the Potomac on August 2, 1862 (28). The "Letterman Ambulance Plan" provided that ambulances of each division moved together, under a mounted line sergeant, with two litter bearers and one driver for each ambulance. Medical officers from regiments accompanied the regiment into battle, setting up stations for the immediate treatment of the injured as near the fire line as possible. The ambulance corps would arrive at the immediate care stations as soon as possible and transport the injured to field hospitals (Fig. 20). As an example of the improvement in the evacuation of the injured under the "Lettermans Ambulance Plan," in the early morning of July 4th, the day following the end of the Battle of Gettysburg, not one wounded Union man remained on the battlefield (29). Similar developments in the evacuation of wounded from the battlefield also took place on the Confederate side.

DISCOVERY OF ANTISEPTIC STRATEGIES, 1848

The basis for antiseptic surgery goes back to the early 19th century. Born in 1818, Ignaz Philip Semmelweis became the head of the first obstetrical clinic at the Allgemeines Krankenhaus (Vienna General Hospital) in 1847. He noted a dramatic difference in the maternal mortality rate due to puerperal fever between the first (13% mortality) and second (2% mortality) obstetrical clinics despite the use of identical techniques within the same hospital. The difference between the two clinics was the identity of the individuals who worked in each clinic, with the first obstetrical clinic being the province of medical students and the second obstetrical clinic being staffed by midwives. Following the death of a friend, Jacob Kolletschka, who contracted an infection from a wound suffered during an autopsy, and manifesting symptoms identical to puerperal fever, Semmelweis took note. He soon thereafter correctly theorized that medical students were transmitting infectious material from the autopsy cadavers on their hands and into the obstetrical clinic where they performed pelvic examinations. He instituted a policy of having medical students wash their hands with chlorinated lime between autopsy and obstetrical Clinic, resulting in a dramatic drop in maternity mortality rate in the first obstetrical clinic.

Semmelweis extended the washing protocol to instruments used on patients in 1848, documenting success in virtually eliminating puerperal fever in the obstetrical ward. Despite this success, the protocols of Semmelweis were largely ignored by others, partly due to the fact that the germ theory of disease had not yet been fully developed; in addition, Semmelweis was often impolite and unrefined in his responses to critics of his methods. **Although Semmelweis was known during his lifetime as the "Pesth fool" (because his birthplace was Budapest), soon after his death, his doctrine (the basis of current infection control practices) was accepted, and he is now known as the "father of puerperal fever."**

Joseph Lister, an English physician born in 1827, is credited with being the father of modern antisepsis, but it was Semmelweis whose epidemiologic discoveries provided the initial insights. Lister had read the work of Louis Pasteur in which Pasteur demonstrated fermentation could occur in the absence of oxygen if there were micro-organisms present. Pasteur had recommended the use of heat, filtration, or exposure to chemical substances to eliminate micro-organisms. With heat and filtration being difficult to use on living patients, Lister experimented with solutions of carbolic acid, spraying the solution on surgical instruments, wounds, and dressings. Lister discovered that the use of carbolic acid greatly reduced the incidence of gangrene and published his findings in *Lancet* in 1867. Lister also read the works of Semmelweis and appropriately credited him, stating, "Without Semmelweis, my achievements would be nothing" (30). **One of the most significant advances in medicine in World War I was the use of antiseptics in surgery.**

By the time of World War I, many other advances in medicine had been made and were incorporated in the treatment of those injured in battle, and old lessons, such as the need to rapidly transport the injured to medical care were improved upon. Two other significant developments incorporated to treat battle trauma included blood transfusion and the diagnostic use of X rays. With the then recent discovery that sodium citrate would hinder coagulation of blood without adverse impact, as well as the discovery of the use of saline to replace blood volume, by the end of the war it was common for traumatized soldiers to receive blood transfusions. This was no doubt facilitated by developments following the work of Francis Rynd of Dublin who developed the first hypodermic trochar in 1844. In 1914, William D. Coolidge of the General Electric Company developed the hot-cathode X-ray tube, which increased the reliability and output of previous X-ray tubes. X rays were widely used to assist in locating shrapnel within the injured as well as to set broken bones at field hospitals.

A French postwar study of the role of rapid treatment for shock demonstrated that delay in treatment of shock had a dramatic impact upon mortality. The French study, *Da Shock Tramatique dans les Blessures de Guerre, Analysis d'Observations* found that a delay in treatment from one hour to eight hours resulted in a rise of mortality rates from 10% to 75% (31). This study served as one of the sources of information for the development of the "golden hour" concept that was advocated by R. Adams Cowley during the Vietnam era.

Pain relief became an important consideration for World War I commanders and leaders, and their concern led to important advances in inhalation anesthesia. Arguably, the most important was to improve the competence of the individuals administering the anesthetics. The volume of casualties was horrific.

Operating rooms were arranged so that a single anesthetist could care for three patients simultaneously, an arrangement that is still utilized today in situations where anesthesiology personnel are limited. In those days, the anesthetist might have been a medical doctor without special training, a nurse anesthetist with accelerated training, or a dentist or corpsman without any specific training whatsoever.

Out of this milieu, a hero in the field of anesthesiology and resuscitation was produced. Arthur Guedel (1883–1956) described the practice as he found it in those days. "The methods are slipshod and careless to a degree that causes an enormous wastage of anesthetic material and occasional accidents which are costly to the government to say nothing of the occasional loss of life of an American soldier . . . A system of suggestions and instructions . . . in the matter of surgical anesthesia would go far toward saving money, time, and life. Guedel found that he would have to do the instructing himself. Guedel developed a cuffed endotracheal tube to allow airway protection from aspiration. He demonstrated the efficacy of this invention by placing a small intubated dog upside down submerged in an aquarium (Fig. 21). He developed training programs for professionals and lay personnel at two key locations to instruct students in airway management and monitoring vital signs and depth of anesthesia.

He developed a chart of the signs of the stages of ether anesthesia, which would become a standard for teaching for 50 years. In order to supervise anesthetic care in several hospitals, he made his rounds by motorcycle and became known as "the motorcycle anesthetist of WWI." Thereafter, the importance of the training and qualifications of doctors and nurses who were responsible for the administration of anesthesia to the troops was recognized by improved rank and conditions (32).

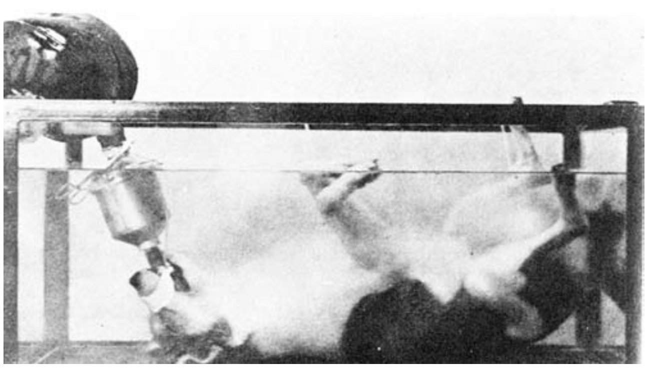

Figure 21 Guedel dunked dog. Arthur Guedel demonstrated the safety of endotracheal intubation with a cuffed tube by submerging his anesthetized pet, Airway, in an aquarium while the animal breathed an ethylene–oxygen anesthetic through an underwater "to and fro" anesthesia circuit.

During and following World War I, inhalation anesthesia was enhanced in many important and enduring ways. Anesthesia machines capable of delivering compressed gases, oxygen, nitrous oxide, and ether vapor were developed in the United States by Gwathmey, in Germany by Connell, and in England by Boyle. Ivan Magill introduced endotracheal intubation in 1918 in order to facilitate reconstructive operations on the face and the neck. Waters introduced carbon dioxide absorption in 1924.

EPOCH OF REGIONAL ANESTHESIA, 1884

The seminal event that started the epoch of regional anesthesia was the report of the use of cocaine for topical anesthesia of the eye in 1884 by Viennese ophthalmologist Karl Koller (1857–1944). Koller was dissatisfied with the available anesthesia of the time for delicate eye surgery. He complained that patients were restless and coughing during surgery, and were in pain and vomiting postoperatively.

He collaborated with Sigmund Freud, a research associate in pharmacology to study the use of cocaine for topical anesthesia in the eye. Austrian explorers had returned with a supply of leaves from the South American coca tree, which they gave to the laboratory. Freud had confirmed the numbness of the tongue when he chewed the leaves, and Koller made the connection that cocaine would also work if dropped onto the conjunctiva. Freud later became famous for psychoanalysis and psychotherapy and never wished to be recognized for his role in regional anesthesia (33).

The famous surgeon William Halstead of Johns Hopkins University was the first to try cocaine for nerve blocks of the upper extremity and face in 1886. Halstead became addicted to cocaine and ultimately died from the effects, not of cocaine but rather of the morphine that his doctors tried to substitute for cocaine to break his addiction. August Bier of Germany was the first to use cocaine for spinal anesthesia in 1898 (34). In subsequent years, regional anesthesia was generally used as an alternative to general anesthesia to allow surgery on patients who were considered too frail for the rigors of ether inhalation.

Regional anesthesia was particularly valuable in war situations where shortages of medical personnel existed. During World War I, as in all wars, trauma and shock were common and unavoidable manifestations. Anesthesia had not yet become a science, and practitioners were frequently ignorant and unskilled. Airways and oxygen for resuscitation were generally unavailable. Limb injuries were frequent and surgical speed was of utmost importance. The correct choice of anesthetic was important. Dr. Cushing, at the Harvard Unit, introduced the phrase "regional anesthesia" and preferred its use because, in his opinion, the complications of general anesthesia like cerebral vasodilatation and hypotension could be avoided.

Spinal and regional anesthesia became increasingly popular. The French surgeon Victor Paruchat strongly advocated spinal anesthesia for all surgery below the tenth thoracic dermatome. Nerve blocks were performed for amputations, rib resections, and upper extremity surgery. For abdominal surgery, many surgeons used combined field blocks with splanchnic nerve blocks. Stovaine (amylocaine) and procaine were popular anesthetics. Some statistics reflect the use of spinal anesthesia in 12% of all operations. However, anesthesiology and surgical traumatologists subsequently became fearful of the hypotension, which inevitably occurred with spinal anesthesia and the exacerbation of shock in hemodynamically unstable patients were occasionally fatal. **In his paper, Captain Geoffrey Marshall wrote that the death rate from anesthesia was due to "giving the wrong anesthetic or giving the right anesthetic wrongly."** He found that, by determining the hemoglobin concentration, he could predict the circulating volume and the patient's ability to safely tolerate a spinal anesthetic (35).

EPOCH OF INTRAVENOUS ANESTHESIA AND ANTIBIOTICS, 1934

The seminal event in the development of IV anesthesia was the report of the use of thiopental for induction of anesthesia in 1934 by John Lundy (1894–1973), who was head of the section of anesthesia of the Mayo Clinic in Rochester, Minnesota (36). As with inhalation and regional anesthesia, several advances led up to the clinical application of IV anesthesia. The syringe was described in ancient Greece and was used from time to time over the centuries. The piston syringe was used for urethral injection of mercurial salts in England by the 1550s for the treatment of syphilis. Indeed, the battleship Mary Rose sank in Portsmith Harbor in 1542 with a load of these syringes on board. Christopher Wren experimented with the syringe in the 1650s to inject opioids intravenously using a quill for a needle and a frog bladder for a syringe (similar to that shown in Fig. 22). Further developments of the hollow needle and the syringe for IV injection by Alexander Wood of Edinburgh in 1853 led the way to more frequent usage.

Fischer of Berlin first synthesized hexobarbital (evipal) and won a Nobel Prize for his work. In 1932 Weese, Schraff, and Reinoff reported on the IV use of Evipal during surgery

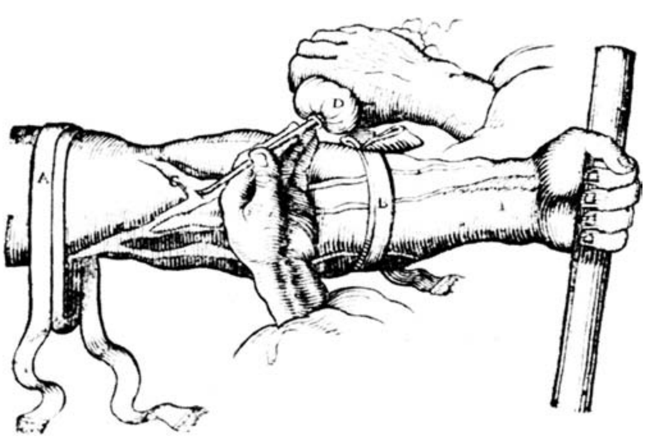

Figure 22 Early illustration of IV infusion apparatus from Major's text of 1667. *Source*: From Major JD. Chirurgia infusoria, Keil, 1667. Courtesy of Wellcome Institute for the History of Medicine, London.

(37). However, their report attracted little attention in Europe, whereas Lundy's report revolutionized the practice of anesthesia all over the world.

The simplicity of IV anesthesia was responsible for its instant popularity and nearly for its downfall. The drugs (evipal or hexobarbital, and pentothal or thiopental) were portable, nonflammable, and required little ancillary equipment. The simplicity of administration implied that anyone who could push the plunger of a syringe could give an anesthetic. The armed forces stockpiled huge quantities in strategic locations such as Tripler Army Hospital in Hawaii, so the drug was freely available when the Japanese struck on December 7, 1941.

During the surprise attack on Pearl Harbor, 2403 soldiers, sailors, and civilians were killed (1227 died on the two battleships, USS Arizona and Utah). Thirteen military and civilian hospitals received 1178 wounded persons on that day. Most wounds were produced by shrapnel and consisted of large lacerations and compound, comminuted fractures. Hypovolemic shock was frequent, adequate supplies of blood and plasma did not exist, and saline solutions were considered contraindicated. In hindsight, the latter is surprising, because Thomas Aitchinson Latta had successfully used saline to treat circulatory shock caused by cholera as early as 1832. Morphine was given in doses of 30 mg, many times repeatedly, because records were not kept. A substantial number of these patients required anesthesia and surgery. Some received thiopental alone as a bolus IV dose of 0.5 to 1.0 g, leading to respiratory depression, cyanosis, and death (38). Oxygen and positive pressure respirations were not available. Artificial respirations were attempted by the Sylvester method popularized for the nearly drowned.

The resulting deaths led to the conclusion that IV barbiturate anesthesia was dangerous for shocked patients suffering from heavy blood loss. The same conclusion was made for regional and rectal anesthesia. Military surgeons concluded that open drop ether was preferred for casualties, especially when experienced anesthetists were not available (39). Bennetts felt that the main problems were lack of oxygen and equipment for administering oxygen, lack of proper fluid resuscitation of shock, and excessive use of morphine (40). By 1944, after the teachings of Adams, anesthesiologists had learned to use the IV anesthetics with proper respect to their pharmacology and with proper resuscitative equipment available (41).

One of the major advances in treating wounded soldiers in World War II was the advent of antibacterial agents such as sulfa and penicillin. In 1935, German biochemist Gerhard Domagk published his findings on experiments with Prontosil sulfonamide to treat streptococcal infections in mice. Subsequent researchers discovered that the active component of prontosil sulfonamide was sulfanilamide. Sulfanilamide proved to be an effective method of combating infection. American soldiers were issued a first aid packet containing sulfa powder and told to sprinkle the powder on any wound.

In 1928, Scottish scientist Alexander Fleming noticed a halo of inhibition of staphylococcus bacterial growth surrounding a mold. He isolated the mold and discovered it was *Penicillium notatum*. After experimentation, Fleming concluded that penicillin could not last long enough in the human body to fight bacterial infection and halted his efforts to develop penicillin between 1931 and 1934. In 1939, Australian scientist Howard Florey and a team of researchers at Oxford University demonstrated the antibacterial action of penicillin in vivo, showing its effect on mice. One of the significant problems with utilizing penicillin was the difficulty in producing sufficient amounts, complicated by renal clearance. Early in the course of the war, it was common to collect the urine of those being treated with penicillin so as to isolate and reuse the penicillin.

In the early 1940s, the chemical structure of penicillin was determined, and Florey, working with biochemist Ernst Chain, discovered a method of mass producing penicillin. By 1945, the production of penicillin was an industrial process in the Allied nations. Fleming, Florey, and Chain shared the 1945 Nobel Prize in medicine for their work on penicillin.

The importance of leaving contaminated wounds open and later closing if appropriate was firmly established in World War II. At the urging of Colonel Edward D. Churchill, the surgical consultant for the U.S. Army in the Mediterranean theater of operations, a program of "early reparative surgery" was established in 1944. Such treatment consisted of delayed primary closure of the wound between the fourth and tenth postinjury days if the wound was clinically assessed to be "clean." "Delayed primary closure" was performed on simple soft-tissue wounds without penicillin therapy and complex wounds (i.e., those involving large volumes of muscle, bone, joint, nerves, or vessels) were closed and 40,000 units of penicillin were administered every three hours. The success of such treatment completely altered the military policy guiding the care of soft-tissue wounds, and these lessons carried over to civilian practice as well.

In 1941, the Birmingham Accident Hospital opened in England, the first hospital set up specifically to treat injured, as opposed to ill persons, becoming the world's first trauma center. The Accident Hospital came out of studies declaring that the treatment of injured persons within England was inadequate and recommended that separate hospitals for the treatment of injured be established. By 1947 at Birmingham Accident Hospital, there were three trauma teams each consisting of two surgeons and an anesthesiologist as well as a burn team consisting of three surgeons. These teams were led by an Australian surgeon, Professor William Gissane. Gissane's leadership was based on four premises. These were separation of the ill from the injured, continuity of care by a single team from the time of admission to the time of discharge, care directed by a senior surgeon, and, lastly, rehabilitation provided as an integral part of the care package and started from the time of admission. Gissane was also ahead of his time, because he recognized the importance of a trained anesthetist as an *integral* part of the trauma team. Consequently, he encouraged the anesthetists to manage not only the airway and breathing but also the circulation. In order that they might fulfill these duties effectively, he relieved them of other duties such as cross-matching blood. In general, the Accident Hospital anesthetists used techniques common at that time. However, they were apparently dissatisfied with the analgesics available, particularly in the prehospital setting, and from 1948 to 1954 frequently gave IV procaine.

EPOCH OF FLUID THERAPY FOR TRAUMA, 1950

The revolutionary proposal to use balanced salt solutions in the treatment of surgical and traumatic shock is one of the most important innovations in the modern care of the surgical patient. This proposal was made in 1950 by a team of doctors including Drs. M. T. Jenkins, Carl Moyer, Tom Shires, and Ben Wilson. In those early days, Ringer's Lactate solution and normal saline were the only choices available. (The story of Ringer's and Hartman's solutions is chronicled in Volume 1, Chapter 11.) The innovative idea changed forever the way we think about fluid therapy in traumatized and surgical patients. In this respect, the proposal in 1950 launched the epoch of fluid therapy of trauma (42).

Before 1950, surgeons and physiologists felt that salt solutions were contraindicated in the traumatized patient, who was said to be intolerant to salt. This prevalent attitude can be traced to the work of Dr. Carl Moyer, a surgeon with an interest in the metabolic problems of the surgical patient. He gave a liter of normal saline to a series of healthy medical students and observed that all the sodium was promptly excreted in the urine. The balance of sodium intake and output was perfectly maintained in the healthy human body. The same salt load was given to anesthetized surgical patients, but they did not excrete the sodium. Under the influence of anesthesia and surgery, the kidneys transiently retained the salt load. He concluded that the patients were intolerant to sodium and recommended that salt be withheld from anesthetized surgical patients. His research was presented at the Massachusetts General Hospital on the occasion of the celebration of the centennial of the introduction of anesthesia in October 1946 and published in *Southern Surgeon* (42).

All influential surgeons and physiologists of the time supported Moyer's recommendation. Traumatized patients were given small amounts of D5W and, if blood loss was excessive, they were given transfusions of whole blood. The turning point came in 1950. A series of critical patients in hemorrhagic shock who received D5W and massive transfusions of whole blood for resuscitation developed high hematocrits, stiff lungs, and pulmonary failure. At autopsy, they displayed a condition named "congestive atelectasis" (43). The authors theorized that the hemoconcentration and congestive atelectasis could be prevented if patients were given simultaneously a fluid that resembled extracellular fluid (in those days, Ringer's lactate). Subsequently, Shires demonstrated the deficit of interstitial fluid, which occurs in hemorrhagic shock in dogs and humans (44). This work validated the use of balanced salt solutions in hemorrhagic shock. Using radioisotopes, Shires demonstrated the acute sequestered edema space (also called incorrectly the "third space") associated with trauma and blood loss. He confirmed the deficit of healthy extracellular fluid, which results from the formation of the edema space. The opinions of surgeons and physiologists were gradually changing. Salt solutions were no longer felt to be contraindicated in surgical patients. Instead they were indicated and, in fact, were life saving (45). Our concepts of fluid therapy in traumatized patients were thereafter changed forever.

We now know that Carl Moyer's anesthetized surgical patients retained sodium from their saline load to compensate for acute sequestered edema and not because the kidneys were unable to excrete salt. His observations were accurate but his conclusions, based on his interpretation of the data, were wrong. Subsequently, in a lecture before the Association of University Anesthesiologists in Dallas, Moyer admitted error and became an ardent protagonist for the use of balanced salt solutions in surgical

Figure 23 Dr. Pepper Jenkins at Parkland Memorial Hospital's recovery room with nursing assistants administering crystalloid solutions to trauma victims and other postsurgical patients in 1960.

patients. Dr. Jenkins applauded this action saying, "It seems quite appropriate to praise a remarkable man, Carl A. Moyer (1908–1970), as a giant among physicians and a leader of great integrity. It must not have been easy for him to reverse published opinions for which he received considerable acclaim" (46). We know that Dr. Jenkins's patients developed higher hematocrits, because they transferred the liquid portion of the transfused whole blood to the extravascular, interstitial space in order to compensate for sequestration of extracellular fluid into the new edema space. Three decades of basic and clinical research have provided a clear understanding of the pathophysiology of acute sequestered edema and have resolved most of the controversies.

The use of balanced salt solutions in the resuscitations of traumatic, hypovolemic shock has been accepted all over the world and has saved millions of lives (47). The revolutionary proposal in 1950 by Dr. Pepper Jenkins (Fig. 23) and his colleagues to give salt solutions to surgical patients changed forever the way we practice medicine and the way we think about fluid therapy in the surgical patient. The most recent development in this concept is the use of hypertonic saline dextran in the resuscitation of traumatic shock. This story and others related to the history of fluid resuscitation are found in Volume 1, Chapter 11.

EPOCH OF PRECISION MONITORING AND RESUSCITATION FOR ANESTHESIA AND TRAUMA, 1986

The seminal event in the development of "precision anesthesia and analgesia" was a resolution adopted by the house of delegates of the American Society of Anesthesiologists, which bound all 30,000 members to a set of "Standards for Basic Anesthesia Monitoring" (48). Anesthesiologists were bound to monitor blood pressure pulse, and electrocardiograms, and evaluate adequacy of respiration and oxygenation. These simple standards were adopted and practical because of recent amazing advances in the technology of monitoring. These two principles fit hand in glove to greatly reduce the mortality of anesthesia. Most recent figures set the mortality at 1:240,000. Once again, the important events leading up to the sentinel event stretch back to the beginnings of the specialty. Joseph Clover (1825–1882) (49) realized that chloroform had many advantages over ether. It was more rapid on induction, more pleasant to breathe, and more potent, that is, it would produce anesthesia in lower concentration. He also realized that, because of its potency, it could rapidly cause overdose and death. He set about to devise a system that would give a known concentration and produce anesthesia without causing death. He realized that he could not accomplish this goal with the open drop technique. He made a rubberized canvas bag with a capacity of 100 L. Using Avogadro's number, he calculated the exact amount of liquid chloroform that he must add to the bag filled with air to have a known concentration. The patient breathed from the bag with a nonrebreathing valve, and the first precision anesthetic was administered (Fig. 24) in 1862. **Modern anesthesia machines deliver precise concentrations of anesthetic drugs and analyze the mixture inhaled and exhaled by the patient to assure that the concentration remains in a safe range.** John Snow designed and built a temperature-compensated vaporizer.

Monitoring of the response of the cardiovascular system to anesthetic drugs had its beginnings with a very famous neurosurgeon from Boston named Harvey Cushing (1869–1939). Cushing had visited Europe and witnessed the blood pressure being taken by the Riva Rocci technique with a cuff and stethoscope. He felt that the technique would have value during anesthesia for his operations, so he insisted that his anesthetist monitor blood pressure and

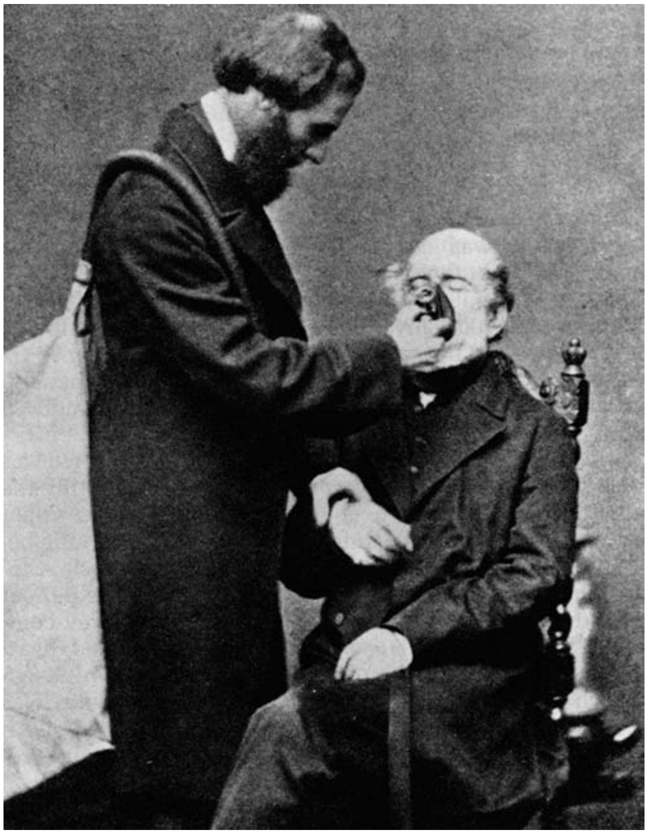

Figure 24 Clover bag anesthesia. Using a Clover bag filled with chloroform, Joseph Clover anesthetizes a patient.

record it on a chart so that Cushing could review it later. The first anesthesia record, dated July 17, 1895, showed that blood pressure and pulse varied widely during the case, but remarked that the patient did not vomit, was not nauseated, and was very quiet at the end of surgery. Keeping a record contributed to analysis, comparison, and development of precise techniques (50).

The commercial availability of the respiratory gas monitor, which could measure concentrations of carbon dioxide, oxygen, nitrogen, and anesthetic gases entering and leaving the patient's lungs, greatly increased the safety of anesthesia. Now, it could be guaranteed that the patient always received enough oxygen to sustain cardiac and brain function; the patient always received enough anesthetic agent to assure unconsciousness but never an overdose; the endotracheal tube was correctly placed; and the ventilation was appropriate.

The final important technological advance in monitoring was the invention of the pulse oximeter (see Volume 1, Chapter 17, and Volume 2, Chapter 8) in Japan by Takuo Aoyagi in 1973, which enabled anesthesiologists to have early warning about conditions leading to hypoxia. Historically, anesthesiologists relied on color changes in the lips or nail beds to detect hypoxia. Aoyagi's machine registered changes in oxygen saturation in a capillary bed long before any color change could be perceived visually. The earlier warning permitted a careful differential diagnosis and corrective action before hypoxia became severe. Precision anesthesia, then, is the balanced use of an induction agent (frequently a barbiturate), a neuromuscular blocking drug, an opioid for analgesia, and an inhalation agent for maintenance hypnosis.

Modern precision anesthesia includes postoperative analgesia. One commonly used technique is an indwelling epidural catheter with periodic or infusion doses of low concentrations of local anesthetic drugs or opioids. The second technique is patient-controlled analgesia, or PCA. PCA is a syringe pump that delivers a prescribed dose of opioids such as morphine or fentanyl whenever the patient feels pain and pushes a button. Both techniques represent remarkable advances in the management of postoperative pain. The quality of pain relief is better with epidural technique in cases where epidural is appropriate. PCA is universally appropriate. It empowers the patient and requires less time from the nursing or physician staff. Both techniques have definitely contributed to modern precision analgesia.

EPOCH OF EMERGENCY MEDICAL SERVICES (CURRENT ERA)

The emergence of the emergency medical services was a social trend which does not have a clear sentinel event or a clear champion. In the two decades from 1950 to 1970, emergency care evolved from simple first aid in the emergency room to sophisticated prehospital and emergency room medicine practiced by well-trained, widely available professionals. Even the experts who participated in the development of the trend do not agree on the genesis (51,52). The development most likely resulted from a growing public dissatisfaction with the prehospital ambulance service combined with rediscovery of the technique of closed chest cardiac compression for resuscitation of cardiac arrest.

Funeral homes and some police or fire departments using vehicles that resembled station wagons provided ambulance services in 1950. The drivers had first aid training, which consisted of bandaging and artificial respiration, using the Sylvester technique (arm lift, chest compression). Once the patient was loaded in the vehicle, the driver hastened to the nearest hospital as quickly as possible. The patient received no attention during the trip, so speed was important. Safar of Pittsburgh and Nagel of Miami developed the concept of paramedics, who would perform emergency care including cardiopulmonary resuscitation at the scene of an accident or illness, communicate with a medical doctor at a base station (usually, a hospital emergency room), and continue to minister to the patient in transit in a specially designed vehicle equipped to carry out these functions.

The concept spread to Europe where the combination of greater population density plus a glut of doctors permitted the luxury of having a medical doctor ride in the emergency ambulance. Both the European system with a doctor on board and the American system based on paramedics claim advantages and both systems have shortfalls. No clear benefit in outcome has been demonstrated. The debate over the superiority of each system continues. In the meantime, the revolution in emergency medical services has brought many changes for the healthcare professions and for the public.

For the healthcare professions, we now have a well-trained, well-equipped, widely dispersed emergency response system, which is activated by a telephone call, usually to 911. The operator who answers will dispatch police, fire fighters, or paramedics. The paramedics who arrive are well trained in rescue, extraction, and emergency care. The ambulances, now called Mobile Intensive Care Units, are modern and well suited for resuscitation at the scene and transit to hospitals, which are chosen for their ability to handle specific clinical problems, not simply the nearest hospital. The paramedics are in contact with a base station where all specialties are available for consultation; for example, an obstetrician can be called for an obstetrical emergency, a pediatrician for a pediatric emergency, etc. On arrival, a medical specialist in emergency medicine assumes the care of the patient. The new specialty of emergency medicine was born in Pittsburgh in 1979 under the leadership of Ronald Stewart and Paul Pepe. As a medical specialty, the growth of emergency medicine has been explosive.

For the public, the widespread publicity surrounding the growth of emergency medical services has led to high expectations and demands. In an interval of 30 years, the public has come to expect that the emergency medical service must be as widespread, responsive, and excellent as police or fire services (see Volume 1, Chapter 7). To have achieved the organization, education, and implementation of the complex emergency medical system in such a short time is truly phenomenal.

SUMMARY

Trauma has been a constant incident to human life. We have seen that ancient civilizations often had surprisingly sophisticated methods of diagnosing and treating victims of trauma. The history of the treatment of trauma also reveals that knowledge from prior civilizations, whether correct or incorrect, has had considerable staying power, as witnessed by the continued influence for centuries of both Galen and the teachings of the Edwin Smith Papyrus through the Hippocratic Corpus. With the advent of the use of scientific methods to examine the human body and its condition, however, more modern times have seen rapid developments in methods to treat traumatized patients.

The first reported general anesthetic was Biblical: "God caused a deep sleep to fall on Adam." For the next million years, mankind was sympathetic for the pain of the injured and sick, but the available plants and medications were not very effective. Plants and extracts were applied to wounds, and wine infused with herbs was offered with little success. The breakthroughs came as sentinel events, which were followed by long periods of completely changed behavior. The epoch of inhalation anesthesia began in 1846 when Morton demonstrated ether anesthesia in Boston. The epoch of regional anesthesia began when Koller dropped cocaine onto the conjunctiva for eye surgery in Vienna Austria in 1884. IV anesthesia began when Lundy injected thiopental for induction of anesthesia at the Mayo Clinic in 1934. The epoch of neuromuscular blockade began when Griffith used curare for abdominal surgery in Montreal in 1942. The epoch of precision anesthesia began in 1986 when the American Society of Anesthesiologists adopted the standards of basic monitoring in anesthesia. The epoch of fluid therapy for traumatized patients began in 1950 when Drs. Jenkins and Moyer introduced the use of Ringer's Lactate as part of the resuscitation of shock. The epoch of emergency medicine services was not associated with a clear sentinel event; rather it began with public dissatisfaction with the available ambulance services coupled with the introduction of closed chest massage for cardiopulmonary resuscitation. All of these developments have led to improved management of pain and lower mortality in injured and critically sick patients.

KEY POINTS

- The history of medical care for trauma is understandably the history of the management of military trauma, because many innovations came as a result of the management of battle casualties or the application of new medical and surgical techniques to battle wounds.
- Among the 48 cases described in the Edwin Smith Papyrus, only one suggests cure by magical methods, with the rest having more rational treatments such as splinting of fractures.
- Humoral theory or developments of humoral theory dominated medicine from the era of Hippocrates up to the time of the Renaissance.
- Under the influence of the philosophical propositions of Aristotle, tutor of Alexander the Great, dissection of corpses became common in Alexandria.
- Upon his death in approximately 203 AD, subsequent work on physiology and anatomy was abandoned, largely due to the view that Galen had said everything that could be said on these areas.
- It was not until Vesalius, a 16th century Flemish anatomist, that many of the anatomical errors of Galen were exposed.
- With the decline of the Roman Empire and the Catholic Church's perceived need to suppress both science and heresy, medical and scientific discovery was stagnated in Western Europe for hundreds of years.
- According to an Arab text, *Tarikh al-hikama*, students were required to pass exams before they could be accredited as Academy physicians. Thus, the Academy of Gundishapur was the first teaching hospital.
- Al-Razi distinguished smallpox from measles and wrote a book on the subject, which demonstrated the differences in the treatment for each disease.
- Avicenna's seminal book, *The Canon of Medicine*, is considered the most famous medical text of the era and was utilized by physicians for centuries, and was employed as a textbook at the Universities of Leuven and Montpellier until around 1650 A.D.
- As a result of the contacts between Christian and Muslim populations and translations of texts, the ideas of the ancients began to become known again in Europe after what can only be called the suppression of these texts by the Catholic church.
- In a break from the traditional means of teaching anatomy, Vesalius utilized dissection as the primary tool of instruction, rather than simply reading classical texts as Galen did. (Fig. 10).
- In Western society, Harvey received credit for discovering that the heart pumps blood through the circulatory system.
- Larrey's most famous innovation was the aforementioned flying ambulance (Fig. 1), but he was, in his own right, a talented physician and surgeon.

- Most ancient attempts to relieve pain consisted of surface applications of plants or organic material.
- The discovery and application of anesthesia has been called the single most important contribution of American medicine to mankind.
- The first public demonstration of ether anesthesia was made before an assembled group of the faculty and students of Harvard Medical School by Morton, a medical student and dentist, who learned the concept from Wells, his partner in dental practice.
- The war with Mexico marked the first use of anesthesia for combat casualties (25).
- Physicians at the time of the American Civil War were without the knowledge of the utility of sterile dressings, antiseptics, and antiseptic surgery.
- Although Semmelweis was known during his lifetime as the "Pesth fool" (because his birthplace was Budapest), soon after his death, his doctrine (the basis of current infection control practices) was accepted, and he is now known as the "father of puerperal fever."
- One of the most significant advances in medicine in World War I was the use of antiseptics in surgery.
- The seminal event that started the epoch of regional anesthesia was the report of the use of cocaine for topical anesthesia of the eye in 1884 by Viennese ophthalmologist Karl Koller (1857–1944).
- In his paper, Captain Geoffrey Marshall wrote that the death rate from anesthesia was due to "giving the wrong anesthetic or giving the right anesthetic wrongly."
- The seminal event in the development of IV anesthesia was the report of the use of thiopental for induction of anesthesia in 1934 by John Lundy (1894–1973), who was head of the section of anesthesia of the Mayo Clinic in Rochester, Minnesota (38).
- One of the major advances in treating wounded soldiers in World War II was the advent of antibacterial agents such as sulfa and penicillin.
- In 1941, the Birmingham Accident Hospital opened in England, the first hospital set up specifically to treat injured, as opposed to ill persons, becoming the world's first trauma center.
- The revolutionary proposal to use balanced salt solutions in the treatment of surgical and traumatic shock is one of the most important innovations in the modern care of the surgical patient.
- The seminal event in the development of "precision anesthesia and analgesia" was a resolution adopted by the house of delegates of the American Society of Anesthesiologists, which bound all 30,000 members to a set of "Standards for Basic Anesthesia Monitoring" (51).
- Modern anesthesia machines deliver precise concentrations of anesthetic drugs and analyze the mixture inhaled and exhaled by the patient to assure that the concentration remains in a safe range.

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Mechanisms and Epidemiology of Trauma

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INTRODUCTION

Injury is a global public health problem and the dominant cause of morbidity and mortality among the young, particularly in industrialized countries. According to the World Health Organization (WHO), there were 5.8 million fatalities due to injury in 2000 (1). Injury is the seventh cause of death worldwide (Tables 1 and 2), and the number one cause of death in the young (ages 1–44) in the United States. Historically, infectious diseases have been the principle source of death and disability. Advances in public health measures during the 20th century have resulted in a decrease in the global burden of infectious disease. Acquired immune deficiency syndrome (AIDS) and related complications created a brief exception to this trend. In the United States, death due to AIDS had temporarily surpassed injury as the pre-eminent etiology of premature death in the 35 to 44 age group (2). However, due to public health education on transmissibility and the development of numerous antiretroviral therapies (Volume 2, Chapter 52), HIV has now returned to the fifth most common cause of death (Fig. 1).

The global burden of all disease (i.e., morbidity and mortality) is depicted in Figure 2. The leading category of worldwide disease is a mixed group of entities termed "other diseases" comprising 32% of all disease. Infectious disease is second (23%) and injury is the third highest cause of global disease (16%) (Fig. 2).

One negative aspect of industrialization has been the commensurate increase in the burden of injury to society. The automobile, a technologic necessity in our present environment, is the leading cause of death and disability in industrialized countries. During 2002, road traffic fatalities were the 11th leading cause of death worldwide. Without changes in approach, it is projected that road traffic fatalities will rise to the third leading global cause of death by the year 2020 (3). The problem is so vast that the WHO has initiated a global prevention and awareness campaign to lessen the burden of injury due to road traffic injuries.

The distribution of global injury-related mortality is depicted in Figure 3. The industrialized region with the highest injury mortality is found in the states that comprise old Union of Soviet Socialist Republics. The rate for this region was 131.5/100,000 population compared to Africa (rate = 118.8) and the United States (rate = 53.8/100,000).

Demographic characteristics such as age, gender, socioeconomic status, and occupation factor into the likelihood of sustaining injury (4). Overall 50% of all injury-related mortality occurs in individuals between the ages of 15 and 44 (5). Yet, over 700,000 children under the age 15 were fatally wounded during 2002 (6). The proportion of elderly patients suffering injury also rises every year, particularly in industrialized countries. Indeed, in the United States, the elderly comprise the most rapidly growing cohort of trauma injury, and they consume a disproportionate amount of trauma funding (7).

In children, road traffic fatalities are the chief source of injury and death. This group of road fatalities includes motor vehicle collisions (MVCs), pedestrian struck by a motor vehicle, and bicycle crashes. While drowning accounts for (10–27%) of childhood injury fatalities, it represents less than 4% of all trauma deaths in people older than 15 years of age. Injuries resulting from MVCs are the foremost etiology of death among adolescents living in industrialized countries whereas, in octogenarians, falls are the predominant cause of trauma death (7).

The leading causes of trauma in industrialized countries are MVCs, whereas in developing countries, interpersonal violence and war account for most injuries. The burden of injury is not evenly distributed throughout the world and is greatly influenced by the socioeconomic status of various regions. The lower socioeconomic and middle socioeconomic regions of any particular country bear 85% of all road traffic fatalities and suffer the highest degree of other injuries as well (4). These areas have fewer resources for injury prevention, medical treatment, and rehabilitation, which also impact negatively on the outcome (4). Individuals of lower socioeconomic status are also at greater risk of injury due to interpersonal violence.

Injury is affected by gender, occupation, and societal views. Injury is the third most common cause of death among males but the eighth leading mechanism of death in females. Males are more likely to be injured due to assaults than females. Despite these figures, females are increasingly becoming victims of interpersonal violence worldwide. Occupations such as farming, fishing, and mining have the highest rates of injury (8).

With the rise of international terrorism, traumatologists are becoming increasingly aware of the pathophysiology and treatment of blast injuries [e.g., due to improvised explosive devices (IEDs)] and mine injuries. In certain regions of the world, mine injuries have been a predominant cause of loss of limb for decades (e.g., Kashmir). Prior to World War II, the majority of landmine victims worldwide were military personnel; today, the majority are civilians, often children. The epidemiologic control of such injuries is very difficult due to the numerous individuals, ideologies, and jurisdictions involved.

Table 1 Global (Worldwide) Causes of Death in 2000

Cause of death	Individuals killed
Lower respiratory disease	3,866,321
HIV/AIDS	2,942,901
Chronic obstructive pulmonary disease	2,522,983
Diarrheal diseases	2,124,032
Tuberculosis	1,660,411
Childhood cluster diseases	1,385,455
Pulmonary malignancies	1,212,625

Source: World Health Organization, 2000.

Table 2 Leading Causes of the Global Burden of Trauma

Cause of death	Individuals killed
Road traffic injuries	1,260,000 (25%)
Other injuries	856,800 (17%)
Suicide	815,000 (16%)
Homicide	520,000 (10%)
Drowning	450,000 (9%)
Poisoning	315,000 (6%)
War	310,000 (6%)
Falls	283,000 (6%)
Burns due to fire	238,000 (5%)

Source: World Health Organization, 2000.

Several factors ultimately influence the outcome of an injured patient. Primary determinants include the etiology and severity of injury, the physiologic state of the patient, and access to acute medical care. Long-term outcome is determined by the patient's overall condition and motivation coupled with access to physical and vocational rehabilitation.

This chapter begins by characterizing the mechanisms of trauma in terms of precipitating agents or vectors, as well as by the biomechanical forces that cause tissue injury. Trauma is further characterized in regard to the intent of injury. The remainder of the chapter surveys the epidemiology of trauma including the scope, demographics, and leading etiologies. The public health prevention programs and strategies aimed at decreasing injuries are also reviewed.

MECHANISMS OF TRAUMA

Trauma is best categorized by utilizing three main descriptors: (*i*) the mechanism of injury, (*ii*) the biomedical forces that created the wound(s), and (*iii*) the intent of injury. All three classifications bear directly on the type, severity, and outcome of the injury (9).

Precipitating Agents of Injury

Trauma mechanisms include mechanical, thermal, electrical, radiation, and blast (a form of mechanical injury). For each of these mechanisms, there are precipitating agents or vectors that produce injury. Mechanical injury can result from blunt force or penetrating trauma. Examples of blunt trauma include motor vehicle crashes, pedestrians struck

	Age Groups										
Rank	<1	1-4	5-9	10-14	15-24	25-34	35-44	45-54	55-64	65+	All Ages
1	Congenital Anomalies 5623	Unintentional Injury 1641	Unintentional Injury 1176	Unintentional Injury 1542	Unintentional Injury 15,412	Unintentional Injury 12,569	Unintentional Injury 16,710	Malignant Neoplasms 49,637	Malignant Neoplasms 93,391	Heart Disease 576,301	Heart Disease 696,947
2	Short Gestation 4637	Congenital Anomalies 530	Malignant Neoplasms 537	Malignant Neoplasms 535	Homicide 5219	Suicide 5046	Malignant Neoplasms 16,085	Heart Disease 37,570	Heart Disease 64,234	Malignant Neoplasms 391,001	Malignant Neoplasms 557,271
3	SIDS 2295	Homicide 423	Congenital Anomalies 199	Suicide 260	Suicide 4010	Homicide 4489	Heart Disease 13,688	Unintentional Injury 14,675	Chronic Low. Respiratory Disease 11,280	Cerebrovascular 143,293	Cerebrovascular 162,672
4	Maternal Pregnancy Comp. 1708	Malignant Neoplasms 402	Homicide 140	Congenital Anomalies 218	Malignant Neoplasms 1730	Malignant Neoplasms 3872	Suicide 6851	Liver Disease 7216	Diabetes Mellitus 10,022	Chronic Low. Respiratory Disease 108,313	Chronic Low. Respiratory Disease 124,816
5	Placenta Cord Membranes 1028	Heart Disease 165	Heart Disease 92	Homicide 216	Heart Disease 1022	Heart Disease 3165	HIV 5707	Suicide 6308	Cerebrovascular 9897	Influenza and Pneumonia 58,826	Unintentional Injury 106,742

Figure 1 The five leading causes of death in the United States in 2002—all races, both sexes. *Source*: Adapted from Ref. 79.

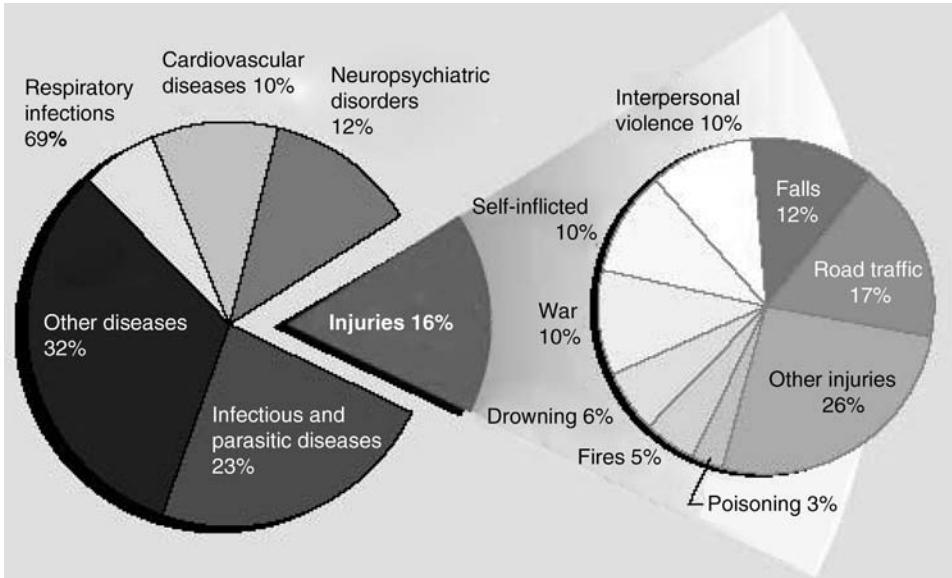
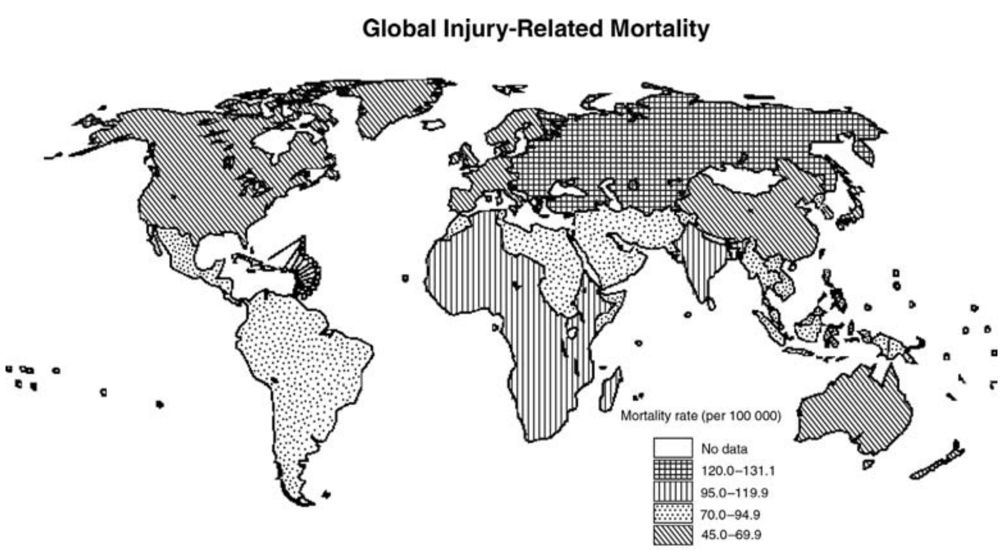


Figure 2 The global burden of disease attributable to injury. Worldwide, infectious and parasitic diseases are responsible for 23% of disease; the second largest single cause of disease is trauma—16% of total. The exploded pie-shaped chart depicts the mechanism of injury for these patients. The category of "other injuries" leads this group with 26%, followed by road traffic fatalities (17%) and then falls (12%). Importantly, intentional injury constitutes 30% of all injury fatalities worldwide. *Source*: World Health Report 1999, Geneva, Switzerland.

by a motor vehicle, and falls. Penetrating injury can occur from knives, gunshot wounds (GSWs), impalement, or bomb shrapnel among others. Thermal injury can result from flame, steam, or chemical burns. Electrical injury can result from either alternating or direct current, as well as from a lightening strike. Blast injury may occur with industrial explosions, bombs, or terrorist activity. Radiation injury can result from medical or research misuse, nuclear



Injury-related mortality rates (per 100,000 population) in WHO regions, 2000												
Africa	Americas		Southeast Asia		Europe		Eastern Mediterranean		Western Pacific			
LMIC	HIC	LMIC	India	Other LMIC	HIC	LMIC	HIC	LMIC	HIC	China	Other LMIC	
118.8	53.8	76.2	96.9	75.0	47.6	131.5	51.1	70.4	56.2	51.5	78.4	

Figure 3 Global distributions of fatal injury by geographic location. Mortality rates are shown for all regions of the world. The shading depicts the mortality range based on the provided key. The table breaks down mortality between high-income countries and low- and middle-income countries within a geographic region. *Abbreviations:* HIC, high-income countries; LIC, low-and middle-income countries. *Source*: World Health Organization, Geneva, Switzerland.

power generation mishaps, nuclear bomb explosions or terrorist attacks.

Biomechanical Forces Generated by Various Mechanisms

The degree of tissue destruction is directly proportional to the amount of energy absorbed by the tissues. The biomechanical forces of injury can be described, in physical terms, as force vectors of energy transmission that result in tissue injury. Cellular destruction can occur immediately due to the transfer of mechanical, electrical, chemical, or thermal energy, or it can occur in a delayed fashion due to secondary mechanisms or prolonged effects. Some forms of energy, such as ionizing radiation, produce both acute injury and chronic disease. Early effects of acute radiation syndrome consist of nausea, vomiting, diarrhea, fatigue, and headache. Exposure to high levels of ionizing radiation can result in a cutaneous burn. This combination of a burn and radiation injury greatly increases the fatality rate of the patient. As the syndrome continues, there are symptoms of bone marrow suppression and worsening gastrointestinal problems such as bleeding and malabsorption. If the patient survives, late effects of ionizing radiation may result in leukemia, lymphoma, or thyroid cancer many years remote from the initial exposure (10).

Each mechanism of injury generates a specific set of biomechanical forces, which act upon body tissues. The type of force, rate, duration, and total body surface area over which the force is applied determine the pattern of injury. These factors, combined with the characteristics of the injured tissue and the physiologic state of the host, determine the extent of injury. The two most common categories of injury mechanisms are blunt and penetrating.

Blunt Trauma

In blunt trauma, a given quantity of energy applied rapidly to a small area of the body typically causes greater injury than if the same energy was applied more slowly and over a broader area. Simply stated, injury occurs when the tissue tolerance is exceeded. Of all the biomechanical forces that can produce injury, mechanical energy accounts for 75% of all injuries (11).

Biomechanical forces may act upon a victim in limitless force vectors and configurations. Despite this, these forces produce a rather predictable set of tissue responses, which include compression, distraction, shearing, and rotation. **The biomechanical forces that result in blunt trauma are most commonly due to rapid deceleration or acceleration.** Either an object that is already in motion strikes the victim or the victim is in motion and strikes another object. A motor vehicle striking a pedestrian is an example of the former and motor vehicle with occupant striking an immovable object, such as a tree, is an example of the latter. In both of these examples, the victim may sustain a soft tissue injury, bony or intracavitary injuries. Injuries to the cervical spine and upper extremity joints are often caused by distraction forces such as hyperflexion or hyperextension. Rotational forces compound the distraction forces that may result in complex and differing spinal injuries, long bone, and musculoligamentous injuries. Shear forces are generated between layers of tissues, which may result in degloving soft tissue injuries, intracavitary solid organ injury, or diffuse axonal injury of the brain (12–14).

Penetrating Trauma

The biomechanical forces associated with penetrating injuries can vary depending upon the type of wounding agent (e.g., knife vs. gun) used. Tissue destruction created by a simple knife wound is relegated to those directly severed by the knife with minimal surrounding tissue injury. However, in the case of a vascular injury, distal organ perfusion will also be at jeopardy.

Penetrating trauma can be characterized as low, medium, and high-energy injuries. Low-energy penetrating trauma can result from a knife or a low-velocity bullet. The injuries are confined to the tract created by the wounding object. Medium and high-energy injuries are caused by higher-velocity bullets and missile fragments.

Gunshot Wounds (Combination of Penetrating and Blunt Biomechanics)

Unique biomechanical forces are associated with GSWs, and these need to be understood in order to fully estimate the wounding potential of a GSW. The biomechanical properties of the bullet—size, shape, mass and density, and the velocity the bullet is traveling—yield the kinetic energy (KE) profile and missile characteristics, which affect the injury pattern. There are many different types of bullets: solid point, hollow point, or fragmenting, all which react differently when striking tissue. The combination of the bullet destruction of the tissue, the energy of the bullet blast effect, and the anatomic location of the GSW are the final determinants of injury.

High-velocity GSWs cause tissue destruction due to the bullet and the cavitary effect created by the associated pressure wave, greatly expanding the zone of injury. **The cavitary effect and subsequent tissue damage from the bullet are more extensive than the missile tract alone, and are dependent upon the KE delivered as the bullet impacts the tissues.**

Far more destruction occurs to surrounding structures from injuries sustained by GSWs than by simple impalement objects such as knives or swords. With a GSW, the primary injury is caused directly by the bullet or fragment, and a secondary injury results from the lateral shock wave (15). The shockwave generates a cavity of injury in the tissue surrounding the primary tract (Fig. 4). In very high velocity GSWs, there is also a forward or leading edge shock wave, which contributes to the injury. The wounding potential is directly proportional to KE of the bullet or missile, and the tissue characteristics. The type of bullet also significantly affects the wounding potential. Hollow point bullets collapse and flatten upon impact, which gives the bullet a larger profile and creates a larger wound. Bullets which fragment or those that "peel outward" and leave jagged edges have a tremendous wounding potential (16,17).

The formula $KE = 1/2\,mv^2$ depicts the relationship between the mass (m) of the bullet in relationship to the muzzle velocity (v) of the bullet. Within the usual categories of bullets, it is the muzzle velocity that has greatest impact upon the KE of the bullet strike (18). Once the bullet has left the gun muzzle, it will have a spin on it due to the rifling of the gun muzzle. The bullet will also begin to have small rotational movements along the axis of flight. Likewise, the bullet may begin to tumble through the air. The final result may be a bullet striking the victim in an orientation different from the expected leading edge of the bullet. A small 22-gauge bullet may strike the victim with a side of the bullet profile, leading to more than the expected

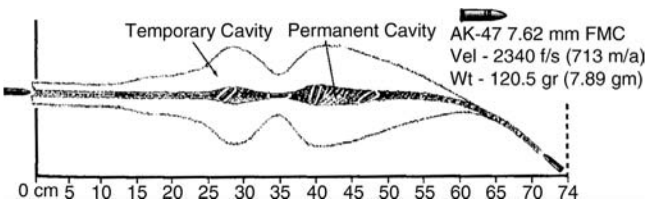


Figure 4 Temporary and permanent cavity created by an AK-47 bullet. The missile (AK-47 bullet) creates a temporary cavity, which is far larger than the permanent lesion. The tissue contained within the zone of the temporary cavity is disrupted with variable degrees of cellular injury. *Source*: From Ref. 15.

tissue damage. Likewise, when the bullet enters the body tissue, it will continue these rotational and tumble motions, causing greater tissue damage.

Deformability of the bullet becomes operative on the tissue in the path of the bullet. If the bullet maintains its shape, it will injure a smaller zone surrounding the path of the bullet. However, if the bullet deforms or implodes, the path of tissue destruction is much wider. This second destructive biomechanical force is related to the "blast zone" of the bullet path. This is the zone of injury, which occurs as a result of the larger pressure wave of energy the bullet imparts upon the tissue. This zone is also dependent upon the KE of the bullet and the tissue characteristics of the victim.

Shotgun wounds differ from bullet wounds in that the type of bullet used is a slug. Within this slug are pellets of very small diameter. The slug disintegrates after it leaves the barrel of the shotgun, and the pellets begin to disperse. These pellets form a circular area of injury on the victim. The size of the circle is dependent upon the distance of the victim from the shotgun as well as the size and weight of the pellets and the muzzle velocity of the shotgun (19).

Energy transferred to the tissues results from both the direct strike of the pellets and the blast force. A victim standing closer to a shotgun blast will have a smaller circle of injury but more massive tissue injury than a person standing further away from the shotgun. The increased injury with closer proximity is mainly a result of the "blast effect" on the surrounding tissue. Blast effect tissue damage (essentially a blunt trauma mechanism) is primarily due to the abrupt pressure changes imparted by the blast effect on the surrounding tissues.

Thermal Injuries

Thermal injuries can result from flame, contact, radiant heat, or steam. All may result in protein denaturation and tissue destruction (also see Volume 1, Chapter 34). **Major determinants of injury are the temperature of burning substance, duration of the contact with the heat source, and the type of tissue exposed.** Flame burns are examined in the context of whether or not the victim was exposed to flames with the burns predominantly due to radiant heat or whether the victim's clothes were on fire, or if the victim was actually on fire. Burns from scalding are dependent upon the temperature of the heated substance and the tissue that has been exposed. Cutaneous tissue in the very young and old tends to be thinner, resulting in a worse burn for any given water temperature and exposure time. Steam, by nature of the heat energy content, is able to rise to a higher temperature than air. Superheated steam, such as used in steam driven turbines, is extremely dangerous and produces extensive, deep burns. Exposure to steam can result in full thickness burns in a few seconds of exposure time. Heated materials other than water (e.g., glass and metals) often contain more heat content and result in more extensive burns.

Inhalation injuries can result from three separate mechanisms. The first source is heat transmitted directly to the upper and lower airways. The human nasal and oropharyngeal anatomy is well constructed to dissipate this heat before it reaches the lower respiratory tract. Nasal concha, turbinates, and hypopharyngeal recesses all act to dissipate the heat. The second is the deposition of particulate matter on the respiratory epithelium. Upper airway filtering of smoke, dust, and debris occurs due to the nasal hairs and concha. Deposition of these particles on the buccal mucosa, tongue, and posterior hypopharynx is the first line of defense. Once breached, the deposition of carbonaceous debris on lower respiratory epithelium may incite bronchospasm (20). The third mechanism of inhalation injury results from the adverse effects of the toxic byproducts of combustion. These include carbon monoxide, cyanide, phosgene, and other hydrocarbons. Steam, due to the high heat content, has the potential to cause serious inhalation burns.

There are two forms of injury that do not follow the pattern of an injury developing after a biomechanical force has been applied. These are best defined as an episode of acute deprivation of a life-sustaining substance associated with the trauma. Mechanisms include (*i*) acute and prolonged loss of oxygen as seen with drowning or asphyxia, and (*ii*) loss of heat (cold-induced injury). Heat loss and cold-induced injury can result in peripheral freezing or "frostbite" (a form of mechanical injury at the cellular level as ice crystals destroy the cellular architecture). Alternatively, cold exposure can cool the central core temperature to the degree that ventricular fibrillation and cardiac arrest occur, ultimately resulting in death. Naturally, cardiac arrest patients are resuscitated following cold exposure if the rescuers witness the arrest, or get to the patient relatively soon thereafter, as cooling can also protect tissues against ischemia-induced injuries (Volume 1, Chapter 40). Ambient temperature, duration of exposure, and type of tissue affected are critical determinants of injury (21). Submersion in cold (conduction), contact with cold, or exposure to wind (convection) will accentuate the heat loss and the cooling effect (Volume 1, Chapter 40).

Caustic Chemical–Related Injury

Acidic or alkaline chemicals produce burns by the denaturing and breakdown of skin and body proteins. **A burn due to an acid substance results in coagulation necrosis whereas a burn due to an alkali substance results in liquifaction necrosis.** These may continue to cause deep tissue damage long after the chemical has been removed from the skin (22). This is particularly true in the case of an alkaline chemical exposure. Certain chemical exposures have a protracted injury pattern. Hydrofluoric acid is a potent acid and is associated with prolonged tissue destruction and electrolyte disturbances. The fluoride ion is capable of chelating calcium, resulting in systemic hypocalcemia. Treatment is directed at neutralization of the acid with lavage followed by systemic administration of calcium, as guided by ionized calcium values obtained with serial arterial blood gas samples (22). White phosphorous exposure may be encountered in the production of munitions, fertilizer, insecticides, and fireworks. It has a low melting point at 101°F and an auto-ignition temperature of 86°F. At temperature above this, the white phosphorus particles will spontaneously ignite and burn. Once this occurs, the exothermic reaction begins, and a massive burn injury can result. Residual particles will continue to oxidize until they have been debrided or irrigated from the wound bed. Covering the white phosphorous with a cool moistened bandage with saline will stop the burning process (22).

Electrical Injuries

Electricity can cause flash burns, extensive soft tissue injury, and cardiac dysrhythmias, including cardiac arrest. The severity of injury is determined by the voltage, duration of contact with the electrical source, grounding, and type of protective clothing worn by the victim. A low-voltage source (less than 1000 V) may result in a thermal burn or neuromuscular injury. Though categorized as low voltage, prolonged contact to these levels can result in cardiac dysrhythmia. A high-voltage source (more than 1000 V) will cause a thermal burn at the entrance and exit sites, but there may also be a secondary zone of injury distal to the entrance site, affecting soft tissue such as muscle, nerve, and tendons. The grounding of the victim is a key determinant of the amount of current and the path the electricity takes within the victim (23). Compartment syndrome, deep muscle, nerve, and vessel destruction are common, as is subsequent rhabdomyolysis. **Because much of the tissue destruction resulting from an electrical burn is internal, the degree of injury is not always initially apparent and is commonly underestimated.**

Flash burns result from an electrical spark igniting the surrounding dust or particulate matter. The thermal burn from a flash is proportional to the intensity of the light emitted and tends to be a high temperature but of short duration exposure. The burns are typically second degree in nature; however, ocular damage should be excluded.

Lightning strikes comprise superhigh voltage (100 million to two billion volts) of very short duration (1/1,000 to 1/10,000 of a second). The amount of current is usually low. In the United States, there are 50 to 300 deaths per year with four to five times as many victims sustaining nonfatal injury. Approximately 75% of these lightning strikes cause permanent neurological impairment. Five major mechanisms of injury result from lightning strikes: (*i*) a direct strike to the victim, (*ii*) a contact injury by touching an object, which is being struck, (*iii*) a side flash or arc from an object being struck, (*iv*) ground current, and (*v*) due to blunt trauma from a falling struck object (24).

Blast Injuries

Blast injuries may occur from industrial or mining explosions and petrochemical explosions. Blast injuries are common in military conflicts and result from bombs, conventional weapons, and from IEDs (Fig. 5) (15). An IED consists of an explosive charge, (often scavenged from conventional munitions), along with electronic or pressure triggers. The terrorists in Iraq have become increasingly sophisticated in their design, often utilizing easily purchased electronic components and cellular phone technology to trigger the charges. Worse, terrorist tactics often include the firing of rocket-propelled grenades (RPGs) at a targeted vehicle after it is disabled by the detonation of an IED (15).

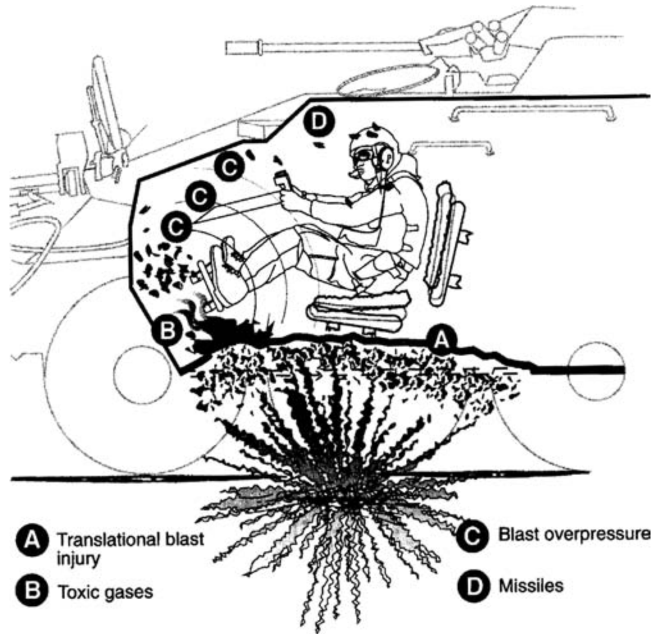


Figure 5 Injuries resulting from mine or improvised explosive device under armored vehicle. Numerous injuries are sustained as a result of defeated armor, (**A**) translational blast injury, (**B**) toxic gases, (**C**) blast overpressure, (**D**) penetrating missile wounds. The armored vehicle shown is a tank with under armor. Humvees and other lightly armored vehicles would sustain greater damage. *Source*: From Ref. 15.

Blast injuries represent a combination of several biomechanical forces (thermal, blast, and ballistic) as shown in Figure 6. After a blast, intense heat and fireball occur at the epicenter. Individuals nearby are often disintegrated, and remaining tissues become charred. The secondary injury following a blast is owing to the increase in the pressure of the surrounding atmosphere that creates a concussive shockwave, which is transmitted through the victim's body and can be a primary cause of injury (15).

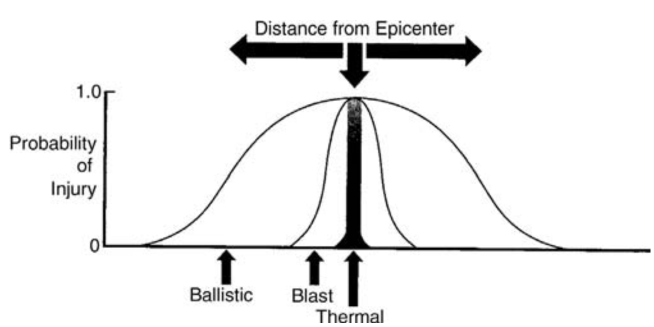


Figure 6 Multiple mechanisms of injury resulting from explosive munitions. The probability of sustaining a given trauma is directly related to the distance from the epicenter of the detonation. Nearby the detonation is an area of intense heat and energy dissipation. Severe tissue destruction and burn occur in this zone. Farther out, the blast effect and shrapnel are the major threats. Far from the epicenter, mainly debris and shrapnel cause injury. *Source*: From Ref. 15.

The blast shockwave causes a temporary "overpressure" condition that can cause soft tissue injury, pneumothorax, pulmonary contusion, perforation of the middle ear or a hollow viscus, and air embolism.

The tertiary wounding affect of a blast is due to flying debris; these may be components of the explosive device (shrapnel) or other debris from the surrounding environment (15). Shrapnel from terrorist bombs may include nails, bolts, glass, and other material. Tertiary wounding can occur from the impact, after a victim is thrown by the force of the explosion. Debris can also fall upon them, resulting in crush injuries associated with a fireball that can cause severe burns.

Radiation Injury

Radiation injury can result from medical substance intended for treatment, as well as from unintended causes such as occupational exposure during research, medical or industrial spills, or as a result of a weapon. Injury can occur from ionizing radiation alone or can involve additional blast injuries if there has been an explosion (25,26). The destructive effects of ionizing radiation depend upon the type of radiation, duration of exposure, and the type of tissue exposed. Types of radiation include alpha, beta, gamma particles, and X rays. Alpha particles are ionizing radiation emitted from the nuclei of unstable atoms. The most common exposure in humans is through radon gas. Alpha particles are of low energy and do not penetrate the skin. However, chronic inhalation exposure with radon can produce disease. Beta particles are not radioactive; rather, they emanate as energy emissions from radioactive atoms. Beta particles can cause damage to cavitary lining cells following ingestion. A common example of beta particle use in medicine is ^{131}I used for thyroid ablation.

Gamma radiation is high-energy ionizing radiation. Gamma photons are pure electromechanical energy and contain about 10,000 times more energy than photons in the normal electromagnetic visible spectrum. Common exposures to gamma radiation come from radiological imaging equipment and radioactive isotopes such as ^{99}Tc, which is used in hepatobiliary imaging, bone scanning, and cardiovascular testing. The difference between gamma rays and X rays is the site of electromechanical emission; gamma rays emanate from the nucleus of an atom, whereas X rays emanate from the electron fields surrounding an atom (25).

Exposure to high doses of radiation can cause both thermal and radiation injury; the radiation effects may be acute or chronic.

Ionizing radiation injury is mediated by energy transference, which results in the formation of highly reactive and unstable free radicals. Oxygen-free radicals, such as superoxide and hydroxyl groups, react with tissue to generate hydrogen peroxide, which causes tissue injury. Long-term effects of radiation are manifested in the damage to cellular nuclear membranes and DNA (26). Massive radiation exposure may result in life-threatening acute radiation syndrome or death. An exposure of 1 to 2.5 Gy of radiation may cause bone marrow depression with pancytopenia. Higher doses of radiation in the range of 8 to 12 Gy may cause gastrointestinal symptoms such as nausea, vomiting, abdominal cramping, and severe diarrhea. Doses of 30 Gy or more may cause vasomotor collapse, respiratory failure, and death. Examples of this high-energy ionizing radiation exposure occurred during the Chernobyl nuclear reactor disaster (27). In this setting, definitive trauma care has to be delayed until the injured patient is decontaminated (see Volume 1, Chapters 4 and 39).

Injury Intent

Determining the "intent of injury" remains one of the principal injury discriptors used by epidemiologists in the development of injury prevention strategies. The intent of the injury may be defined in terms of either the victim or the perpetrator (28) and is broadly separated into two classifications: intentional and unintentional.

Intentional

Intentional injuries occur when individuals deliberately harm themselves or other people. Examples include assault, homicide, and suicide. Injuries resulting from the use of legal force or acts of war are also categorized as intentional injuries. Drugs and alcohol are often contributory factors (29). In a recent study on the epidemiology of traumatic brain injury (TBI), gender, minority status, age, substance abuse, and residence in a zip code with low average income were all associated with intentional TBI (30).

During 2000, the WHO estimated that there were 1.7 million deaths due to intentional injury, representing 3% of all deaths globally (31). There is considerable regional variation in the incidence of violent, intentional injury ranging from 61/100,000 population in the African continent to 22/100,000 in the Eastern Mediterranean.

Victims of both unintentional and especially intentional trauma have a high incidence of psychopathology (32). Victims of intentional trauma have significantly lower intelligence scores than either unintentional injury or elective surgery patients (32). The high incidence of unemployment, alcoholism, and illicit drug abuse in victims of intentional injury suggests opportunities for injury prevention programs (32). However, addressing the underlying psychological disorders is most important in reducing the likelihood of becoming a trauma victim.

Prevention of intentional injury is one of the most difficult public health problems because of the multiple social, economic, and psychological factors involved.

Unintentional

Unintentional injury is a wound sustained without any malicious intent. Examples of unintentional injuries include road traffic injuries, falls, most drownings, and burns. Road traffic injuries may be due to MVCs (including motorcycle crashes), pedestrians struck by a motor vehicle, bicycle crashes, and other injuries. Approximately, 70% of global injury fatalities are due to unintentional injury. The intentionality of an injury cannot always be accurately determined. Likewise, intentional and unintentional injuries may not be mutually exclusive (31,32).

The prevention of unintentional injury focuses upon education, enforced use of restraint devices, and improved control of environmental factors (i.e., roadway maintenance, lighting, clear lane markings, and signage, etc.).

SCOPE OF INJURY AND DEATH DUE TO TRAUMA

The WHO estimated that there were 50 million deaths from all causes worldwide during 2000. The leading causes of death worldwide are depicted in Table 1. Injury fatalities comprised 12% (5.1 million) of these, ranking injury as the

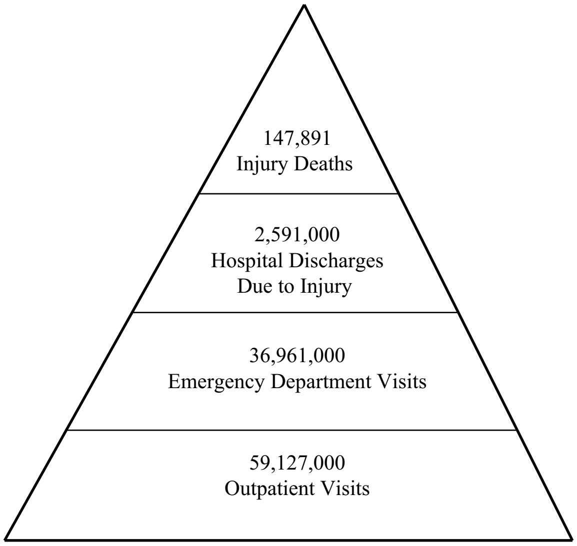


Figure 7 Injury pyramid. The actual number of deaths is small compared with the total number of hospitalizations, but chronic disfigurement as well as mental and physical injury occurs in greater numbers. Greater still are the numbers of patients who are involved in trauma but never admitted. *Source*: Adapted from Ref. 37.

third leading cause of death (33,34). The global injury fatality rate was 97.9/100,000 population. When adjusted for age, injury is the leading cause of death in the group aged 5 to 44 (33). Males are fatally injured twice as often as females (rate; 128.6 vs. 66.7/100,000). For every injury-related death, there are an estimated 30 patients seriously injured and another 300 treated for less serious injuries as depicted by the injury pyramid figure (Fig. 7) (33). In addition, a large number of injuries go unreported. The predominant mechanisms of injury worldwide are provided in Table 2.

Nonfatal injuries were the fifth leading cause of disease worldwide. During 1998, there were 117,680,000 nonfatal injuries, which correspond to 6% of all diseases (33). Using age-adjusted data, injury ranks as the chief cause of both fatal and nonfatal disease in the group aged 5 to 44.

International injury mortality rates vary widely, ranging from a low of 25/100,000 in Hong Kong to a high of 195/100,000 in Russia (34). Motor vehicle fatalities are the leading cause of injury deaths throughout most of the world. An exception is Africa, where war remains the chief cause of injury fatalities.

By comparison, the United States reported 2.4 million deaths due to all causes of disease (2000) (35). There were 144,010 (6%) deaths due to injury, which corresponded to an overall injury fatality rate of 54.5/100,000 (36). This is 45% lower than the global injury fatality rate (11,37). Males were fatally injured 2.4 times more frequently than females (rate: 77.9 vs. $32.2/10^5$), which is similar to the global distribution of injury by gender (33,38,39). Injury was the fifth leading cause of death following heart disease, cancer, cerebrovascular disease, and chronic obstructive lung disease. Age-adjusted fatality data reveal unintentional injury to be the leading cause of death up to the age of 34. In the 35- to 44-year-old group, injury is surpassed only by malignant neoplasia and the acquired immune deficiency disease as the leading cause for death. If both intentional and unintentional injury deaths are combined, injury fatalities are the leading cause of death from ages 1 to 44 (40). The top five causes of death in the United States, subdivided by age groups, are provided in Figure 1.

In the United States during 2000, fatal injuries comprised 66% (97,860) of unintentional injuries and 34% (53,349) of intentional injuries. The leading mechanisms of unintentional fatalities were MVCs 43% (41,994), fall 14% (13,332), and poisoning 13% (12,757). Fatal intentional injuries were due to suicide 55% (29,350), homicide 31% (16,765), and legal intervention 14% (7462).

During the same time period, there were 40,447,000 injury-related visits to emergency departments. Of these, 76.4% (30,907,000) were due to unintentional injury and 5.7% (2,229,000) due to intentional injuries. The remaining 6,875,000 (17.4%) nonfatal injuries could not be classified by intent. The chief cause of unintentional injury was falls (19.9%) followed by motor vehicle-related injuries (12.3%). The chief cause of intentional injury was assaults (82.5%) (41,42,43).

The financial cost of unintentional injury in the United States during 2001 was estimated to be $516.9 billion. The sources of this cost were (*i*) direct healthcare costs (29% of the total expenditure), (*ii*) lost economic productivity, either temporary or due to permanent disability (41%), and (*iii*) costs associated with fatalities (30%). A further breakdown of these costs is as follows: economic costs due to lost wages and productivity ($266.8 billion), direct medical expenses ($95.2 billion), administrative expenses ($74.1 billion), motor vehicular damage ($49.2 billion), employer costs ($21.4 billion), and fire losses ($10.2 billion) (41,44,45).

Injury Pyramid

The injury pyramid emphasizes the reality that mortality statistics only represent the tip of the iceberg, because most episodes of trauma and violence are not reported.

Injury ranges from serious and life threatening, requiring hospitalization or operative procedures, to simple injuries that can be treated by the patient or by a local clinic. The mandatory requirement to report fatalities makes it easier to obtain data on fatal injuries. Nonfatal serious injuries are often recorded in trauma registries and in hospital discharge data. Less serious injury, such as those requiring only emergency department visits, is typically recorded only at the local treatment facility. Outpatient injury visits are recorded at the physicians' office. Thus, central collection and processing of injury data become more difficult as the severity of injury lessens.

Although the easiest to quantify, fatal injuries are only a small fraction of total injuries. The full scope of injury may be visualized as a pyramid with fatalities represented by the smallest, upper portion of the pyramid (44,46). Depicted in Figure 7, the injury pyramid of the United States (2000) has a top layer of 148,209 fatalities, a second level of 2.5 million patients who are seriously injured and require hospitalization, a third level of 40.4 million patients who sought treatment at an emergency department, and a base of 89.9 million patients who were treated at local physicians' offices or at home (37). This illustrates that the true scope of injury is much wider than implied by injury mortality data alone.

Years of Productive Life Lost and Disability Adjusted Life Years

The crude mortality rate approximates the incidence of fatal disease at any point in time. All deaths are given equal importance or weight. A time-based measure, such as years of potential life lost (YPLL), adds significance to premature deaths and the loss of productive economic life (47). In this fashion, injury deaths may be viewed as "expected productive years" lost to society (44,48).

Trauma is responsible for the vast majority of YPLL in the United States. In the United States, the Centers for Disease Control (CDC) uses 75 years of age as the upper limit of an expected economic productive lifespan. If a patient dies from any disease before reaching age 75, the YPLL may be calculated by subtracting the age at death from 75. For example, a fatally injured 25 year old will have 50 YPLL. Although injury is not the leading cause of death in the United States, it accounts for more premature deaths and YPLL than any other disease. Injury exceeds heart disease YPLL by 22-fold, cerebrovascular disease by eight-fold, HIV infection by four-fold, and malignant neoplasm by two-fold. A breakdown of injury by intent reveals that unintentional injury accounted for an estimated 2.1 million YPLL in 2000 and intentional injuries accounting for another 1.1 million years. Worldwide, injuries accounted for 10% of global mortality in 1990, and 15% of YPLL (49).

Another measure of the effect of disease includes the disability-adjusted life years (DALYs). The DALY is used to quantify the years lived with a disability of specified severity and duration. One DALY is the loss of one year of healthy life due to either death or disability. For the DALY calculation, a "premature" death is defined as one that occurs before 82 years of age for females and 80 years for males. These ages are derived from the life expectancy at birth in Japan, which has the world's longest-surviving population (50). In this way, it is possible to obtain a more accurate indication of the effect of a disease on an individual and a population. The WHO uses YPPL and DALY in its report, "The Global Burden of Disease" (50). This report is one of the most comprehensive global epidemiologic studies of injury. Injury is ranked ninth in DALYs (1990), but the WHO estimates that injury will move to third as a leading cause of DALYs worldwide by the year 2020.

Trauma Data Base Organizations and Coding

Several data sources and organizations are devoted to the study and prevention of injury. Table 3 contains a list of some of these organizations and related web sites. The complexity of data acquisition and analysis mean that national and international injury data have to be reported with a two-year lag period. The CDC Division of Injury Prevention and Control is one of the largest research centers in the world. It maintains multiple data sources, references, and links to other injury organizations (41,51). It also maintains a computer program for obtaining both fatal and nonfatal injury information for the United States. These programs called WISCARS (2,38) and WONDER (43) are probably the best examples of ongoing injury data surveillance. Specific injury data for each state are also available (52).

Worldwide data are best obtained from the WHO Division of Injury and Violence Prevention. The headquarters is in Geneva, Switzerland, but much of the injury, violence data, and publications can be accessed through the World Wide Web (53). Recent comprehensive works include *The Global Burden of Injury* (5) and *Violence and Public Health* (53). Traumatologists must become more actively involved in injury prevention and utilize these aforementioned resources (54).

The WHO has developed a method of coding disease. It is a standardized method of coding to enable accurate collection of statistics on disease incidence and prevalence. Injury data starting in 1998 utilize the ICD-10 coding system (55,56), though most medical coding is still using ICD-9 in 2006. Several methods of characterizing injury are utilized (Volume 1, Chapter 4). However, the injury severity score (ISS) is one of the most commonly employed method. **Improved data collection systems result in improved comprehension of the epidemiology of trauma and increased ability to institute preventative strategies.**

Table 3 List of Injury Prevention and Control Agencies

National Highway Traffic and Safety Administration	www.nhtsa.dot.gov
National Crime Victimization Survey–Bureau of Justice	www.ojp.udok.gov/bjs
National Electronic Injury Surveillance System	http://www.cpsc.gov/library/neiss.html
U.S. Consumer Product Safety Commission	www.cpsc.gov
National Hospital Discharge Survey	http://www.cdc.gov/nchs/about/major/hdasd/nhdsdes.htm
National Center for Health Statistics	http://www.cdc.gov/nchs
Uniform Crime Reports–FBI	http://www.fbi.gov/ucr/ucr.htm
National Youth Violence Prevention Resource Center	www.safeyouth.org
Safe USA	www.cdc.gov/safeusa
National Safety Council	www.nsc.org
The World Health Organization	www.who.org
The United Nations	www.un.org
The Pan American Health Organization	http://www.paho.org
Centers for Disease Prevention and Control (CDC)	www.cdc.gov
CDC–National Center for Injury Prevention and Control	www.cdc.gov/ncipc
Institute of Medicine	http://www.iom.edu
WISQARS, a CDC-automated morbidity and mortality reporting system	www.cdc.gov/ncipc/wisqars/default

Abbreviation: FBI, Federal Bureau of Investigation.

DEMOGRAPHIC FACTORS

Injury affects all age groups and both genders, irrespective of socioeconomic status. Each group has specific injury rates and patterns, and knowledge of these relationships is important for the planning of both acute trauma care and injury prevention programs (57). Fatal injuries are most prevalent at the extremes of age. Elderly patients, aged 75 or more, have the highest injury fatality rates of any age group. Nonfatal injury rates follow a slightly different pattern. These injuries are more evenly distributed through ages 1 to 34, and then decrease until age 85. The nonfatal injury rate increases in patients 85 years and older, approaching rates similar to the 15 to 24 age group.

Age specific risk factors influence injury occurrence, type, and pattern. These include types of activities, risk-taking characteristics, violent behavior tendencies, occupation, and the physiologic state of the patient. For example, children are more likely than any other age group to be struck by a motor vehicle. Underdeveloped driving skills combined with risk taking plays an important role in motor vehicle crashes in the 18- to 24-year-old population. Spinal cord injuries due to diving are most common in this age group. Aggressive interpersonal behavior in those aged 15 to 34 contributes to the high incidence of assault-related injuries. Falls and suicide become leading causes of injury with advancing age.

Age-Specific Injury Mechanisms

The mechanisms of both intentional and nonintentional injures vary by age, and the traumatologist should be familiar with these trends (Fig. 8).

In 2002, the leading cause of death in the United States among children less than one year of age was congenital abnormalities. In this group, unintentional injury was the seventh leading cause of death, and the most common mechanisms of unintentional injury were falls, being struck by an object, and burns. Leading mechanisms of fatal injury included mechanical suffocation, followed by motor vehicle crashes, drowning, fires or burns, falls, and poisoning.

In ages 1 to 14, the leading cause of injury deaths was unintentional trauma (Fig. 1), and the specific mechanisms were MVCs followed by drowning. Almost half of the children who died in a MVC were not using child restraint seats. Two-thirds of children under the age of four involved in a fatal MVC were in a vehicle driven by someone who was intoxicated. Between the ages of 10 and 14, suicide was the third leading cause of death, demonstrating an alarming increase of 109% between 1980 and 1997 (51). Children under the age of 15 were involved in 30% of the nonfatal, and 11% of the fatal incidents involved a pedestrian struck by a motor vehicle. One-third of all bicycle fatalities were seen in ages 5 to 14, and 140,000 children were treated in the emergency department for TBI due to bicycle crash. Nonfatal injuries in ages 1 to 14 were caused most commonly by falls and being struck by an object.

Motor vehicle crashes were the leading cause of death among those aged 15 to 24. Intentional injury in the form of suicide and homicide was the second and third leading cause of injury death in this age group. This age group had the second highest fatal MVC rate (27.3/100,000), which was second only to the 75 and older age group (rate: 29.4 deaths/100,000). Nonfatal injuries were led by MVCs, being struck by an object, and falls.

In the 25- to 64-year-old age group, the pre-eminent cause of injury death was MVCs. This was followed by poisoning, fall, fire, and burn. Nonfatal injury in the 25- to 34-year-old group was caused most commonly by being struck by an object followed by MVC. Among those aged 35 to 64, the top cause of fatal injury was MVCs followed by poisoning. Nonfatal injury in this age group was caused most commonly by fall followed by being struck by an object.

In the 65 and older age group, the foremost mechanism of fatal injury is fall followed by MVCs (58). Nonfatal injury was caused most commonly by fall followed by being struck by an object. Patients 65 years and older have the highest fatality rate for pedestrians struck by a motor vehicle. Twenty percent of all suicides occur in this age group as well.

Socioeconomic Status

The socioeconomic status of a patient contributes to the likelihood of sustaining an injury. Within the United States, there is a great disparity in the incidence of assault and homicide between ethnic groups. An African-American is nearly seven-fold more likely to die from homicide than a

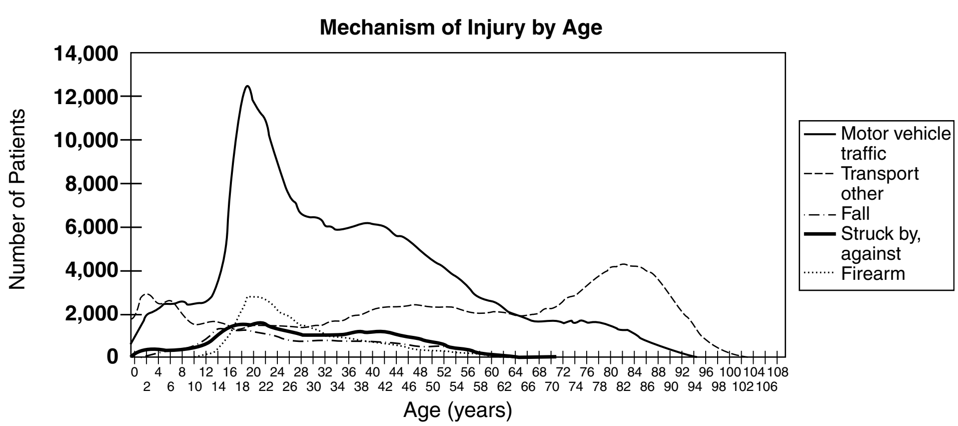


Figure 8 Number of patients injured stratified by mechanism and age in National Trauma Data Bank, 2005. Total $N = 857,428$. Motor vehicle accidents are the most common cause of injuries for all ages except for the very young (<2) and the elderly (>65). In both cases, falls are the most common mechanism of injury. *Source*: Adapted from Ref. 58.

Caucasian (59). The injury rate in many injury categories is higher in this ethnic group than any others. People of lower socioeconomic status are more likely to be a victim of an assault, a phenomenon which occurs worldwide (60). However, when groups of patients are stratified for equivalent socioeconomic status and education, there is no difference in the injury rates between different ethnic groups (61). A pedestrian struck by a motor vehicle is twice as likely to be Hispanic American as Caucasian. This may be explained by the higher rate of walking seen in the former ethnic group. MVC and poisoning are the first and second causes of death in this ethnic group. Homicide is the second most common category of death, behind MVCs, in the 15- to 34-year-old Hispanic age group. Native American Indians are three times more likely than Caucasians to be struck by a motor vehicle. The risk for an injury due to a residential fire is also the highest in this group.

Gender

Trauma remains predominately a disease of males. However, there is an increasing trend of violence against women due to assault worldwide.

Males are 2.4 times more likely than females to be injured. Different mechanisms of injury have differing male to female ratios of injury. Males are at higher risk for injury from MVCs, motorcycle collisions, fall, drowning, and homicide. Females are more likely to attempt suicide than males; yet, males more frequently succeed in committing suicide. Females are more often assaulted or murdered by an intimate partner than males. Females are more likely to experience a fall that results in a fractured hip; however, males 65 and above are more likely to experience a fatal fall (51).

Males are more likely to engage in riskier behavior in daily activities, sport, and drinking alcohol, not wearing safety belts and becoming involved in violent acts. Thus, males are twice as likely to sustain a TBI or spinal cord injury. The rate for nonfatal injury is greater in males in all age groups up to the age of 70 (Fig. 9). Up to the age of 75, males account for 60% of fatal injuries. Above the age of 75, the female fatalities reached 55% of the cohort.

LEADING MECHANISMS OF INJURY

In the United States, each day 405 people die from injury. Another 7500 are hospitalized, and 162,000 are injured seriously enough to inhibit them from their normal activity. Approximately, 92% of the latter group will seek medical care. Of the 405 fatalities, one-third result from MVCs, one third are due to "other causes" of injuries, and the remaining third are due to intentional injuries (suicide and homicide) (40,62,63).

Unintentional Injuries

Motor Vehicle Collisions

There were 1.2 million fatalities due to road traffic injuries during 2002. There were an additional 20 to 50 million people injured in this same time period. A global cost for these injuries is estimated at US $518 billion (64). There is a great disparity in the amount of dollar expenditure for the care of these victims, which is dependent upon the economic status of the country they live in. Of the 518 billion dollars spent for road traffic injuries, 86% is spent by high-income countries (HIC) with only 65 million dollars spent in all low-income countries.

In the United States, motor vehicle injuries, fatal and nonfatal, are the leading cause of injury. In 2001, there were 42,900 deaths and 2.3 million nonfatal injuries due to MVCs. The death rate was 15.4/100,000 per year, a decrease of 17% since 1990. The majority of injuries (71%) arose from either a collision between motor vehicles or a motor vehicle striking a fixed object. The estimated cost of these crashes and injuries was $199.6 billion in 2001. This cost is broken down into wage and productivity loss, medical expenses, property damage, employer costs, and administrative costs. **The National Safety Council estimates that for every motor vehicle related–death, there is an associated cost of $1 million.** For every serious nonfatal disabling injuries, there is a cost of $36,000 and, for minor crashes and injuries, the cost is approximately $6,500.

Every age group seems to have specific risk factors associated with these types of injuries. In young children, the lack of use or improper use of child protective safety

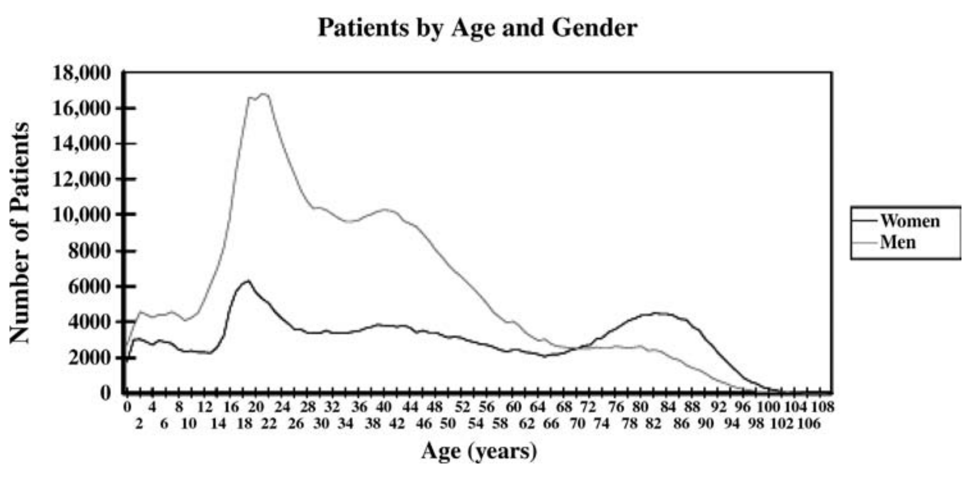


Figure 9 Number of men and women injured grouped by age in National Trauma Data Bank, 2005. Total $N = 917{,}265$. Men are more likely to be injured than women until age 70, after which women experience more injuries. *Source*: Adapted from Ref. 58.

restraints remains a problem. Fifty percent of the fatally injured children under six years of age were not wearing protective safety restraints. Teenage drivers take risks and lack mature driving skills. This group has the highest fatal crash rate per driver than any other age group (964/100,000 licensed drivers). Risk factors for elderly motor vehicle crash-related injuries are related to the aging process and include diminished visual and auditory acuity. Diminished flexibility in the cervical and thoracic spine impairs the ability to look over the shoulder, a requirement for safe driving. People over the age of 75 have the highest crash death rate of 29.4/100,000 people per year.

Alcohol was a factor in 38% of all fatal motor vehicle injuries. The 21- to 24-year-old age group, closely followed by the 25- to 34-year-old age group, accounted for the highest rate of fatalities in which alcohol was involved. Cell phones and other types of electronic devices all compete for the driver's attention and may contribute to motor vehicular crashes. On average, only 32% of American drivers fatally injured were using safety belts at the time of the crash. Motor vehicle passengers are even less likely to wear a safety belt (41,42).

Pedestrians Struck by a Motor Vehicle

Approximately 15% of all injuries in the motor vehicle category are caused by motor vehicles striking pedestrians. There were 90,000 nonfatal and 5800 fatal pedestrian injuries in 2001. There was a 12% decline in pedestrian fatalities from 1990 to 2001. The case fatality ratio was 9%, making pedestrian injuries the most lethal of all types of motor vehicle-related injuries. Approximately, 60% of the pedestrians were struck as they attempted to cross a street. Twice as many injuries occurred when the victim was crossing the street between intersections. Another 8% occurred while pedestrians were walking along the roadside. Alcohol consumption, with blood alcohol levels of 0.10 or more, was found in 33% of the fatal pedestrian injuries in those patients aged 14 or greater. An age disparity between nonfatal and fatal injures exists with respect to age. Children under the age of 15 experienced 32% of all nonfatal and 12% of the fatal injuries, whereas, people aged 65 and older experienced 8% of the nonfatal and 22% of the fatal injuries (41,42,51).

Falls

Falls account for 20% of all unintentional injuries. They are the second leading cause of death in all unintentionally injured victims and the second leading cause of spinal cord and TBI. Falls disproportionally affect the very young and the very old. The elderly are particularly vulnerable to falls (Volume 1, Chapter 37). In fact, 87% of all fractures in the elderly population are due to falls. In 1998, hip fractures resulted in 300,000 hospital admissions for fall-related hip fractures. In the greater than 65 year old age group, there were 9600 deaths due to falls during 1998 (51). Falls were the leading cause of death in those aged over 75 and exceeded motor vehicle crash fatalities in this group by 1.5- to 2-fold. Falls constitute one-third of all nonfatal unintentional injuries in the elderly. Fatal injuries due to falls are one of the most evenly distributed mechanisms of injury by gender. Environmental hazards such as stairs, uneven surfaces, poor lighting, and slippery surfaces may all contribute to a fall. In the elderly, diminished eyesight, flexibility, as well as problems with gait and balance may contribute to a fall. Twenty percent of all fatal falls in the elderly occur in a home.

Drowning

Drowning is the second leading cause of death from unintentional injuries among children and young adults. It has been estimated that, for every child who drowns, four more are admitted to the hospitals and 16 are treated in the emergency rooms. In the United States, there were 3300 deaths due to drowning in 2001. Approximately, 80% of the fatalities were males. There were 496 drowning fatalities in children aged one to four. This group also had the highest drowning fatality rate (2.4/100,000 people). In the 1- to 14-year-old age group, drowning was the second leading cause of death. African American children aged 5 to 19 had a drowning rate of 2.5-fold higher than Caucasian children (51). In 89% of boating-related deaths caused by drowning, the victim was not wearing a personal floatation device. Drowning victims due to swimming pool mishaps continue to be a significant problem. **Most drownings of 1- to 4-year-old children occur in residential swimming pools, typically when the child is unsupervised (even for a "few moments").** The average duration that the child was not under direct supervision when a drowning occurred was only five minutes.

Bicycle

There were 750 fatal and 54,000 serious nonfatal bicycle-related injuries in 2001. There was an additional 450,000 injured to a lesser degree who sought medical treatment. Approximately, 80% of all bicycle injuries involve a collision with a motor vehicle. Males are seven times more likely to be involved in a bicycle crash than females. Victims greater than 15 years of age comprise 75% of all bicycle-related injuries with age group 25 to 44 experiencing the greatest number of fatal injuries. Use of a bicycle helmet reduces the risk of serious head injury by 33%; yet, they are worn by just 38% of adults and 69% of children. Approximately 140,000 children were treated in the emergency department for head injuries caused in bicycle crashes.

Fires and Burns

Injuries due to fire and burns have been decreasing steadily since 1989. In 1994, 1.4 million people sought medical attention for burns, 60,000 were hospitalized, and 4100 fatally injured (see Volume 1, Chapter 34). Every 27 minutes, someone is killed or injured in a home fire. Approximately, 70% of all fire deaths occur at home. In 1999, there were 383,000 residential fires, which fatally injured 2900 people and injured another 16,000 people in the United States (51). The age group of 75 years and older had the highest death rate of 6.5/100,000 people.

Intentional Injuries

The WHO defines violence as "the intentional use of physical force or power, threatened or actual, against oneself, another person, or against a group or community, which either results in or has a high likelihood of resulting in injury, death, psychological harm, maldevelopment, or deprivation" (62). Intentional injury often occurs without premeditation; an interpersonal conflict may escalate particularly if the individuals are under the influence of drugs or alcohol (63). Access to a lethal weapon increases the chance of a suicide attempt becoming fatal. In these instances, there appears to be a "disparity between intended behavior and intended consequences" (51,62,64).

According to the Pan American Health Organization, death due to violence was the leading cause of death in the Americas in the 5- to 24-year-old age group. By comparison, in the United States and Europe, motor vehicle crash fatalities were the leading cause of death in this age group. During 2000, in the United States, there were 10 times as many nonfatal intentional injures compared with fatal intentional injuries (1.6 million nonfatal vs. 16,765 fatal) (63,64).

Assault

Injuries can result from simple assault, robbery, aggravated assault, or homicide. In the United States, there were approximately 1.6 million (6.4%) emergency department visits resulting from violence in 2000 (65), with 61% of these occurring in males (1,021,118) and 39% in females (650,361). Eighty one percent of the assaults were due to blunt trauma, while 8% were due to a cutting or piercing instrument, and 3% were due to a GSW (66). The type of assault and weapons used impact on the outcome. Overall, there were 94 nonfatal assaults for every homicide. When the assault is committed with a firearm, there were only four nonfatal injuries for each homicide (67).

Child abuse includes physical abuse, neglect, sexual abuse, psychological abuse, and medical neglect. In the United States during 1988, approximately 900,000 children experienced or were at risk for child abuse or neglect, and 1100 were fatally injured (51). In infants and young children, TBI from the "shaken baby" syndrome is a leading cause of death.

Intimate partner violence or domestic violence is a significant problem worldwide. One in three females injured from domestic violence requires medical treatment. The cost of this type of injury is not only measured in medical dollars but also in the emotional harm that is caused to the patient as well as any children in the family. In the United States during 1998, 32% of all female homicide victims were murdered by an intimate partner, whereas, only 4% of males were killed by an intimate partner.

Homicide

Although homicide rates have dropped in recent years, they remain unacceptably high. During 2000, there were 16,765 victims of homicide in the United States. From 1992 to 1998, for every homicide victim over the age of 12, an additional 121 people were injured, 16 of them severely. Firearms were used as a weapon in 82% of the homicide victims aged 15 to 19. **There is a great socioeconomic disparity with respect to homicides, as those of lower socioeconomic status are at a far greater risk of a fatal assault than people of greater economic means (58,68).**

Globally, an estimated 563,000 homicides (rate: 10.5/100,000) occurred in 1990. Males were affected three times more than females (rate: males 13.6 vs. females $4.0/10^5$) (30). Geographically, the highest rate of homicide was found in the sub-Saharan African region (rate: $44.8/10^5$). In this region, males aged 15 to 29 experienced the highest homicide rate in the world (rate: 156.7/100,000) (63).

Suicide

The increasing incidence of suicide in the adolescent age group demands greater public attention. In 2000, 29,250 suicides occurred in the United States, and this was the 11th leading cause of death there. Fifty seven percent were due to firearms, 19% due to suffocation, and 17% due to poisoning. Males aged 65 or older commit 84% of the suicides, yet suicide was the second leading cause of death in the in the 25- to 34-year-old age group. In the 20 to 23-year-old age group, males are seven times more likely than females to commit suicide. White females attempt suicide four times more often than white males; however, white males are four times more likely to die from a suicide attempt.

Table 4 Type of Injury[a]

Type of injury	Frequency	(%)
Penetrating	645	35.7
Blast	425	23.5
Blunt	410	22.7
Unknown	84	4.6
Crush	63	3.5
Mechanical	49	2.7
Thermal	48	2.7
Undetermined	21	1.2
Other	16	0.9
Chemical agent	10	0.6
Bites/stings	8	0.4
Degloving	8	0.4
Electrical	7	0.4
Heat injury	7	0.4
Inhalation	3	0.2
Multiple penetration system	3	0.2
Total	1807	100.0

[a]A casualty may have more than one type of injury. These numbers are based on 1530 level III casualties.
Source: From Ref. 15.

There were an estimated 264,108 patients treated in hospital emergency departments for nonfatal self-inflicted injuries. Of these, 170,222 (65%) were due to poisoning, 65,256 (25%) due to sharp instruments, and 3016 (1%) involved a firearm. Sixty percent (158,464) of the 264,108 visits were considered to be suicide attempts (58,69). An estimated 650,000 patients seek help for suicide attempts each year (70).

Worldwide in 1990, there were an estimated 786,000 suicides (15.5/100,000). The highest rate of suicide was in China with a rate of 30.4/100,000. Globally, elderly people 75 years or older had the highest suicide rates (63).

War-Related Injuries

Not all war-related injuries are strictly intentional. For example, "friendly fire" or injuries sustained during wartime but not due to hostile intent (e.g., motor vehicle accident, fall from a height, etc.) are not categorized as intentional. However, the vast majority of injuries result from hostile intent. Data from the recent American combat operations in Iraq and Afghanistan 2003–2004 demonstrated a wide spectrum of injuries with the majority due to penetrating trauma, with blast effect and direct blunt force being the other chief biomechanical causes (Table 4) (15). The single most common mechanism in terms of vector were IEDs, followed by MVCs, GSWs, grenade [including rocket-propelled grenades (RPG)], and shrapnel (Table 5) (15).

PUBLIC HEALTH APPROACH TO INJURY PREVENTION

Nearly all "accidents" are preventable, and numerous potentially controllable events contribute to the typical

Table 5 Mechanism of Injury[a]

Mechanism of injury	Frequency	(%)
IED	310	18.4
MVC	207	12.3
GSW	188	11.1
Grenade (includes RPG)	170	10.1
Shrapnel/fragment	141	8.3
Unknown	119	7.0
Machinery or equipment	95	5.6
Fall or jump from height	90	5.3
Mortar	84	5.0
Burn	53	3.1
Aggravated range of motion	31	1.8
Land mine	29	1.7
Others	27	1.6
Knife or other sharp objects	21	1.2
Helicopter crash	19	1.1
Blunt object (e.g., rock or bottle)	17	1.0
Pedestrian	16	0.9
Free-falling objects	14	0.8
Bomb	12	0.7
None	12	0.7
Unk	10	0.6
Environmental	9	0.5
Exertion/overexertion	5	0.3
Flying debris	5	0.3
Building collapse	2	0.1
Hot object/substance	2	0.1
Altercation, fight	1	0.1
Total	1689	100.0

[a]A casualty may have more than one mechanism of injury. These numbers are based on 1530 level III casualties.
Abbreviations: GSW, gunshot wounds; IED, improvised explosive devices; MVC, motor vehicle collision; RPG, rocket-propelled grenades; Unk, unknown.
Source: From Ref. 15.

accidental event. By conventional wisdom, injury is considered to be an unplanned, unfortunate, and nonpreventable event. However, considerable research data now demonstrate the preventable nature of most "accidental" injuries (71,72). Just as a deliberate exposure to a very infectious respiratory disease increases the likelihood of contracting the disease, personal attitudes and behaviors influence the chance of injury. These attitudes need not be deviant; they may simply reflect the choice not to use available safety equipment such as seatbelts or a child safety seat. Likewise, not wearing a bicycle or motorcycle helmet, not utilizing smoke detectors in a residence, or not fencing in swimming pools may lead to injury. Risk-taking behavior in driving or with sporting events increases the likelihood that an injury will occur.

Referring to a traumatic event as an accident implies randomness associated with the event for which the individual has no control. Some individuals are described as "injury prone," implying an inability control their life or injury risk. Injury research has shown this to be a misconception. Rather, injury is an event that can be prevented and controlled like other forms of disease.

Early work on "accident prevention" was undertaken by John Gordon and William Haddon (71,73). Their pioneering research in establishing the root causes for injury and quantification of the injury potential associated with key events surrounding the accident serve as the foundation for modern injury prevention and control measures. They recognized that injuries are not caused by accidents but by predictable events and hence are potentially preventable. Injury prevention is an evolving science devoted to the elimination of injuries. Early work included motor vehicular safety issues leading to improved road safety standards, lighting, and intersection design. Work on fire safety led to better construction design and fire sprinkler systems. Baby crib slats were placed closer together so that children could not get their heads caught between the slats and choke. Injury control aims to limit the severity of injury once an event occurs by engineering safety features into consumer products. Early work in motor vehicle injury control led to the placement of seat belts in motor vehicles, the use of tempered glass for front windscreens, and the use of padded dashboards.

Haddon created a matrix to describe any injury in terms of basic components and phases (5). He broke down injury into four basic components: (*i*) the host, (*ii*) an agent or vector, (*iii*) the physical environment, and (*iv*) the social environment in which the injury occurs (48). The host refers to the person who becomes injured. The agent or vector is the object facilitating the injury, for example, a motor vehicle, bicycle, gun, etc. The physical environment refers to the physical or environmental conditions. When driving a motor vehicle, the physical environment may

Table 6 The Haddon Matrix as Applied to a Motorcycle Crash

"Accident" components	Phases		
	Pre-event	Event	Postevent
Host or human factors	Inexperienced and intoxicated motorcyclist	Not using a helmet, not wearing gloves and leathers.	Age and physical conditioning of the cyclist
Agent, vehicles or vector	Motorcycle	Condition of the motorcycle and the tires and brakes	Integrity of the motorcycle and guard rails along the curve
Physical environment	Slippery winding road, with no banked turns	Trees or poles near roadside, oil in roadway	Guard rail and highway design
Socio-cultural environment	Societal attitudes about drinking and driving	Emergency medicine response system	Trauma systems for acute and rehabilitative care

consist of dry road surface in daylight, or it may be a slick rain-soaked roadway at night. The social environmental factors include whether the driver is intoxicated, is driving too fast at the prodding of a friend, or is distracted by music or by other passengers in the vehicle.

The injury event itself can be broken into three phases: (*i*) the pre-event phase, (*ii*) event phase, and (*iii*) the post-event phase. The four basic components described by Haddon (listed above) are analyzed during each phase of the injury event. An example of a Haddon (73) matrix is provided in Table 6. This method of researching an injury event highlights casual factors and identifies interventions that might prevent or control an injury event.

EYE TO THE FUTURE

Recently, the public health approach to disease control has been applied to the study of injury prevention (74). There are four primary tenants using this approach. First, the problem is identified and quantified using an injury surveillance program or review of existing injury data. Second is the identification of risk factors or causal agents that may contribute to an injury event. Third is the design, the trial implementation, and evaluation of an intervention project designed to reduce injury burden. Fourth is the wider implementation of injury prevention and control. These four principles are summarized by evaluation, education, engineering, and enforcement. Table 7 lists several successful injury prevention and control projects (63,75–77).

Improved data collection and data management systems involving trauma statistics are underway. The National Trauma Data Bank (NTDB) and CDC are two examples of increasingly accurate and relevant data management systems being used to track injury statistics. The National Injury Surveillance System (NISS) is another database that is increasing the scope and the number of centers available to better capture data that are currently not being logged.

The WHO has pushed for underdeveloped countries to report injury data and for improved standardization of data. Interpersonal violence is a major area of often uncaptured statistics, and improved capture is being sought at the national level in the United States by the CDC and globally by the WHO.

SUMMARY

This chapter surveyed the mechanisms of trauma in Section II and the epidemiology of trauma in the remaining sections. The demographics of trauma are characterized in terms of intent, YPLL, and by demographics including age, gender, and socioeconomic factors. Trauma is still a disease that affects young males to a disproportionate degree, but several trends have recently been discovered: (*i*) there is an increase in adolescent suicides; (*ii*) women are increasingly becoming victims of interpersonal violence; (*iii*) the elderly are increasingly becoming involved in trauma and have a far higher mortality for any given ISS.

The focus upon prevention needs to be intensified. It is now increasingly understood that accidents are seldom random, and consist of numerous factors that can be modified in order to decrease the risk of injury. The prevention of intentional injury is the most difficult, as it requires changes in the root causes of violent interpersonal behavior (involving numerous complicated psychological factors). Family and school-based programs have been developed to assist in conflict resolution and mentoring programs. After school and after dark supervised youth activities, suicide crisis counseling, and intimate partner counseling are just a few of the additional programs designed to address these issues (78).

The role of the healthcare profession in the reduction of injury is underutilized. Acute medical treatment and

Table 7 List of Injury Prevention and Control Projects (Past and Present)

Program	Target group	Intervention	Outcome
Bicycle helmets	Youth bicyclists	Safety helmet usage while riding	Decreased head trauma
Smoke detectors	All people	Smoke detector in the home	Decreased burns and smoke inhalation to inhabitants
MADD	General public	Decrease the incidence of driving while intoxicated	Lowering DWI rates and decreasing motor vehicle crashes
Playground safety	Youth	Improve the safety of playground equipment and surfaces	Decrease playground injuries
Swimming pool safety	Toddlers and young children	Fence in swimming pools and increase awareness of drowning	Decrease the rate of childhood pool drowning
Auto safety restraint system usage	Automobile occupants	Use of seat belts and shoulder harness	Decrease the severity of a motor vehicle crash
Child restraint system usage	Children and toddlers	Proper use of child restraint systems	Decrease the severity of a motor vehicle crash
Prevention of falls	All ages, but particularly in the very young and elderly	Improved lighting, nonskid floors, barred lower windows	Decrease the incidence of fall related injuries
Burn prevention	All individuals	Fire awareness campaigns; stop, drop, and roll campaigns	Decrease the incidence of burns and smoke inhalation

Abbreviations: DWI, driving while intoxicated; MADD, Mothers Against Drunk Driving.

rehabilitation will reduce the burden of injury, but the prevention and the control of injury are likely to have an even greater impact. Healthcare professionals should undertake research to define the scope of the injury problem, to delineate the biomechanics of injury, and to design prevention programs. Healthcare professionals can support local interest groups involved in injury prevention projects. Counseling, education, and behavioral modification techniques will enhance social awareness and reduce risk taking (29).

While natural disasters such as earthquakes, tsunamis, and hurricanes or tragedies such as plane or train crashes bring injury to the forefront of the news and our minds, the daily morbidity and the mortality resulting from injuries to individuals go relatively unnoticed. Trauma continues to go on as the "silent epidemic" identified by the Public Health Service four decades ago. Although the organization and the quality of medical care have advanced, injury prevention still lags behind. **Injury prevention and control begin with one person, one idea, and a purpose of mind to change the status quo.**

KEY POINTS

- The leading causes of trauma in industrialized countries are MVCs, whereas in developing countries, interpersonal violence and war accounts for most injuries.
- The degree of tissue destruction is directly proportional to the amount of energy absorbed by the tissues.
- The biomechanical forces that result in blunt trauma are most commonly due to rapid deceleration or acceleration.
- High-velocity GSWs cause tissue destruction due to the bullet and the cavitary effect created by the associated pressure wave, greatly expanding the zone of injury.
- The cavitary effect and subsequent tissue damage from the bullet are more extensive than the missile tract alone, and are dependent upon the KE delivered as the bullet impacts the tissues.
- Major determinants of injury are the temperature of burning substance, duration of the contact with the heat source, and the type of tissue exposed.
- A burn due to an acid substance results in coagulation necrosis, whereas a burn due to an alkali substance results in liquifaction necrosis.
- Because much of the tissue destruction resulting from an electrical burn is internal, the degree of injury is not always initially apparent and is commonly underestimated.
- The blast shockwave causes a temporary "overpressure" condition that can cause soft tissue injury, pneumothorax, pulmonary contusion, perforation of the middle ear or a hollow viscus, and air embolism.
- Exposure to high doses of radiation can cause both thermal and radiation injury; the radiation effects may be acute or chronic.
- Prevention of intentional injury is one of the most difficult public health problems because of the multiple social, economic, and psychological factors involved.
- The prevention of unintentional injury focuses upon education, enforced use of restraint devices, and improved control of environmental factors (i.e., roadway maintenance, lighting, clear lane markings, and signage, etc.).
- The injury pyramid emphasizes the reality that mortality statistics only represent the tip of the iceberg, because most episodes of trauma and violence are not reported.
- Trauma is responsible for the vast majority of YPLL in the United States.
- Improved data collection systems result in improved comprehension of the epidemiology of trauma and increased ability to institute preventative strategies.
- The mechanisms of both intentional and nonintentional injures vary by age, and the traumatologist should be familiar with these trends.
- Trauma remains predominantly a disease of males. However, there is an increasing trend of violence against women due to assault worldwide.
- The National Safety Council estimates that for every motor vehicle–related death, there is an associated cost of $1 million.
- Alcohol was a factor in 38% of all fatal motor vehicle injuries.
- Most drownings of 1- to 4-year-old children occur in residential swimming pools, typically when the child is unsupervised (even for a "few moments").
- There is a great socioeconomic disparity with respect to homicides, as those of lower socioeconomic status are at far greater risk of a fatal assault than people of greater economic means (58,68).
- The increasing incidence of suicide in the adolescent age group demands greater public attention.
- Nearly all "accidents" are preventable, and numerous potentially controllable events contribute to the typical accidental event.
- Injury prevention and control begin with one person, one idea, and a purpose of mind to change the status quo.

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Prehospital Care and Trauma Systems

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INTRODUCTION

The management of prehospital care has dramatically improved over the last two decades. Although the organization varies in different regions of the world, each of the various systems has evolved to incorporate the life-saving lessons in resuscitation and monitoring relevant to their unique situations and local conditions.

The earliest records of organized prehospital care are attributed to Greek military operations, including the advent of triage, prehospital care, and hospital ships that were used to transport wounded soldiers home to Greece. More recently, the Napoleonic Wars, the American Civil War, the World Wars, as well as the Korean and Vietnam conflicts have witnessed continued progress toward more structured battlefield care, both in terms of the quality of field hospitals and flow of evacuees from the battlefield (1–3). During the recent wars in Afghanistan and Iraq, the management of prehospital care has been streamlined even further by American and coalition forces. Indeed, under optimum conditions, patients can now be transported to Landstuhl Army Regional Medical Center in Germany within 12 hours of a major battlefield injury occurring anywhere in Iraq or Afghanistan. Furthermore, patients with certain injuries (e.g., major burns) can be off-loaded from one airplane immediately after transport from Iraq and landing in Germany, and placed directly onto another plane waiting on the runway tarmac for an immediate flight back to Brooke Army Hospital in the United States, arriving 12 hours later (total time from battlefield in Iraq to Brooke Army Burn Center in the United States $\leq$24 hours).

The concept of initial treatment of life-threatening injuries and evacuation to a center with adequate resources for definitive care now forms the basis of trauma management for both military and most rural civilian emergency medical service (EMS) systems. Each country has developed an approach to respond, extricate, assess, treat, and transport patients suffering from trauma. This typically includes an organized dispatch with dedicated emergency phone numbers for the public to access. Different levels of response are now available based upon need, ranging from basic first responders, to paramedics, to prehospital physicians. New techniques have been developed to safely evacuate injured patients from crumpled vehicles, damaged structures, and precarious geographic regions. Increased specialty training in managing the specific needs of the trauma patient in the field has been developed in response to lessons learned both on the battlefield and in civilian settings. Additionally, research data are increasingly used to assess and validate the management of trauma patients.

This chapter reviews the various prehospital systems, including staffing models and the training of the EMS providers. The basic philosophies and management strategies of prehospital providers are also examined by contrasting models of care. Particular attention is placed on the quality of communication between the various entities. Finally, the integration of prehospital care and definitive management centers (including a comparison between military levels of care and the "trauma system" concept) is discussed.

MODELS OF PREHOSPITAL TRAUMA CARE

Staffing Models of Prehospital Care

Background

Prehospital care is structured around the world according to a variety of models, with variable integration of local rescue systems and the regional health care organizations. In the United States and Canada, the ambulance services are integrated within local fire departments and first response systems, whereas, in European countries, the ambulance service is typically separated from the rescue services. Ambulance services may exist as separate contracts with the hospitals or with the national or local health systems, which purchase ambulance services for the population. The degree of physician-led input and direction varies, especially with respect to the actual involvement of physicians in prehospital care.

United States and Canadian Model

In the United States and Canada, the prehospital care systems are basically incorporated into the emergency response system. A call for assistance is made and emergency resources are dispatched. The training and expertise of the initial responder varies based on local staffing, ranging from volunteers in rural and remote regions to multitiered responders in urban settings. Typically, the fire rescue crews, also known as "first responders," are dispatched, bringing with them the necessary extrication tools in addition to equipment for basic life support (BLS). Simultaneously dispatched with the first responders is an ambulance capable of transporting the patient as well as providing additional medical assistance.

Many regions will have a greater number of staffed first responder units (e.g., the traditional fire suppression units) than ambulances. Therefore, they typically arrive earlier and initiate patient care until the arrival of the ambulance transport unit. The level of care provided by the first responders is usually BLS, but the responders can include highly trained paramedics who are able to deliver advanced life support (ALS); this varies depending upon the geopolitical region. The training of the personnel arriving with the transporting ambulances is typically at the paramedic level if responding to trauma calls.

In addition, aeromedical resources are available in many regions. These are often staffed with an even higher level of care, which can include a flight nurse or a flight physician. Regions that utilize air transport include those with prolonged transport times, difficult extrication sites, limited ground resources, or limited availability of ALS care by ground units. These regions are typically sparsely populated, mountainous, contain vast archipelagos, or traverse relatively long distances (see Volume 1, Chapter 7). Flight crews allow for "ALS-backup" in regions with scarce or no availability of ALS ground crews, or in sparsely populated regions remote from hospitals that would deprive the region of their ALS resource if patient transport out of the region by ground were required.

Medical oversight of prehospital care runs the gamut from required physician presence at the scene, to protocols requiring real-time physician input through telecommunication, to merely retrospective involvement (e.g., follow-up quality assurance performance reviews). The oversight in most North American regions incorporates a combination of both "on-line" (prospective) and "off-line" protocol driven care with (retrospective) medical review. Most of the ambulance services in the United States have an on-line medical control via radio or cell phone system directly to an available in-hospital radio nurse or physician, with direct on-scene intervention by physicians being quite limited. In fact, statutes have recently been enacted in some jurisdictions that specifically limit the participation of physicians in field operations, particularly in a "good Samaritan" role.

A number of systems in the United States have moved toward off-line medical oversight in which treatment algorithms are created, and paramedics operate on standing orders under these protocols. Physician back-up consultation is available via radio, but is rarely used in this setting (4–6). The dynamics of organized labor representing field medical and personnel, and a persistent aggressive agenda for operational independence of medical oversight, must be balanced by appropriate physician oversight for optimal patient care to occur. However, for a variety of reasons (e.g., lack of organization and interest), physician groups have not always provided the community-wide leadership required. As an editorial side note, the authors believe that statutes should not limit physician participation at any level of care.

Central European Model

In many European countries, the ambulance service is separated from the rescue crews. Ambulance teams may exist as separate entities that are subcontracted and operated by hospitals, or by the national or local health systems (which contract ambulance services to care for the population). Initial responses are essentially "house calls" made by rescue personnel, with ambulances being called only if necessary. These ambulances, whether ground- or air-based, are often dispatched from the hospital with an "on-board" physician as one of the responding crew members. In this model, the physician and technology are brought directly to the scene, providing a high level of emergency care to the patient before they arrive at the hospital (7). When physician evaluation occurs in the field, patients are triaged earlier, and can even be admitted directly to inpatient specialty services.

The German system of physician-based prehospital care is representative of the best of those found throughout Europe. The German system integrates rescue teams, ambulance services, and hospital care, especially at level-I trauma centers. The German prehospital system is based on a combination of basic transport ambulances, ambulances staffed with emergency physicians, and physician-staffed helicopters. These ambulances and helicopters are not competitive, but complementary; helicopters are often based at a level-I trauma center to ensure the immediate availability of a physician for prehospital trauma care and rapid transport. The extent of the physician involvement varies from country to country, with Germany and France having the most extended physician-based systems; Scandinavian countries have partial coverage of physician-staffed ambulances and helicopters; and the United Kingdom has sporadic coverage by prehospital physicians. The majority of physicians involved is typically anesthesiologists; but to some extent also include emergency physicians, internists and trauma surgeons. The United Kingdom also employs general practitioners. They all have supplementary and specialized training of varying content and duration.

Comparison of Prehospital Staffing Models

The majority of prehospital investigations of both paramedic-based systems and physician-based systems have been conducted as observational studies without control groups. Few studies with control groups have made comparisons between the two models of care. One study compared the overall trauma systems of an American air transport program with the German air trauma system (8). Although it was noted that there were more invasive procedures utilized by the German physicians, there was no significant difference in overall mortality between the two systems; 11.3% for the American System versus 9.5% in the German system. Common methods of scoring the magnitude of trauma injury sustained by an individual patient include a "physiological system" [e.g., the revised trauma score (RTS)], and an "anatomical system" [e.g., the trauma injury severity score (TRISS)], both fully discussed in Volume 1, Chapter 4.

A TRISS analysis showed that the German model would produce an additional 2.5 survivors for every 100 patients treated (9). Other studies have used TRISS analysis to compare prehospital treatment by physicians and paramedics. The study of the London Helicopter Emergency Medical Service (HEMS) did not find differences in the overall mortality among injured patients treated by HEMS, compared with trauma patients treated by ordinary ambulance crews, including paramedics (10). However, among the subpopulation of the most severely injured, there was a trend toward improved survival among the HEMS-treated group. This study may have been more of an indictment of helicopter-based transport in urban environments than an evaluation of on-site care provided by physicians as against that provided by paramedics.

Until the late 1990s, when the U.K. National Trauma database had gathered data for TRISS-analysis, all TRISS-based studies were compared to the Major Trauma Outcome Study (MTOS) from the United States. However, the U.S. study population in the MTOS patient group differed from the U.K. group in several ways including the epidemiology of trauma, the severity of injuries, mechanism of injury, age, and comorbidities. These differences made direct system comparisons quite challenging.

In the evaluation of a trauma helicopter service that was established in Amsterdam, the group of patients with intermediate severity injuries had improved survival from 11% to 17% when treated by physicians (11). Australian studies of trauma patients, and patients with head injuries, also showed improved survival among patients treated by the physician-staffed helicopter or physician-staffed ambulances compared with those treated by ordinary ambulances (12–14). Other work has shown that invasive procedures are performed more often and more successfully by trained physicians than paramedics (15). Conversely, a Canadian study based on an expert panel reviewing a number of trauma deaths found treatment performed by prehospital physicians to be harmful, especially when there is a long "on-scene time" (16). Additional work comparing three programs, each serving a level I-trauma center, one with "Physician ALS," another with "Paramedic ALS," and yet another with "Emergency Medical Technician-BLS," concluded that there was no survival advantage of an on-site physician, or even ALS level care over BLS when occurring in an urban setting (17).

There are numerous observational studies that evaluate the beneficial effect of paramedic-based prehospital care on trauma patients. However, a rigorous review of the prehospital trauma literature found no randomized controlled trials (RCTs), quasi-randomized controlled trials, or controlled before-and-after studies comparing effectiveness of ambulance crews with ALS training against crews with any other levels of training (excluding physicians) in reducing mortality and morbidity in trauma patients (18).

In summary, the question of whether a physician-based or paramedic-based system is superior for the management of field trauma patients depends upon both the prehospital environment and the hospital system accepting the patient. It is generally agreed that physician-assisted prehospital care is most beneficial in rural settings, where the time between injury and definitive care is long, whereas in urban settings, rapid transport directly to the trauma center has the highest survivor yield, regardless of the level of training of the EMS provider. **Prehospital levels of staffing, whether using paramedics or physicians, are dictated by local need and financial feasibility.**

Skill Levels and Training of Prehospital Providers

The training levels of the prehospital care providers is diverse; ranging from lay people acting as volunteer responders to varying levels of emergency medical technicians (EMTs), paramedics, flight nurses, or physicians. The level of staffing in a region is often dependent on local need, finances, and available resources. In remote regions, volunteer first-responders are more common with BLS-level EMTs assisting with transport, while paramedics are more common in suburban and urban areas.

Advanced first aid and CPR training for first responders takes approximately 48 hours, compared with 128 hours of training for an EMT-Basic. The scope of care of the EMT focuses on spinal immobilization, basic airway management, and defibrillation. An intermediate level EMT (i.e., "EMT-1") is often utilized more in rural areas, where paramedic coverage is difficult to maintain. They have additional skills above those of the EMT-Basic, being able to initiate intravenous (IV) fluids and administer certain medications. Paramedic training consists of over 500 hours of classroom and laboratory training as well as a minimum of 480 hours of field training. Paramedic "scope of practice" varies from state to state, and may incorporate advanced airway management (including oral and nasal intubation as well as needle cricothyrotomy), interosseus access, needle thoracostomy, and an increased scope of medication use. In addition, and on a limited basis, courses have recently become available which are designed to create a critical care medicine (CCM)-trained paramedic (paramedic CCM), which involves placement of central lines, chest tubes, initiation and management of vasoactive and inotropic infusions, and so on. Although physicians' medical education is far more extensive than that required for prehospital providers, medical school didactics rarely include field-specific training or other aspects of prehospital trauma management. Accordingly, physicians learn the bulk of their prehospital training during residency, and as part of their daily routine in hosipitals.

Although many European and U.S. trauma systems now involve physicians in prehospital care, there are yet some areas such as the United Kingdom where doctors rarely venture into the prehospital environment. As a result, the trauma team receiving the patient may have little understanding of the nature of the prehospital environment, extrication requirements, hazards and difficulties of treating patients outside of the hospital, scope of skills of prehospital care providers, and difficulties in transporting patients with major trauma.

In trauma management, especially in severely injured patients, the efficacy of ALS performed by ambulance crews has been questioned (18,19). One criticism appears to be the challenge of maintaining sufficient numbers of advanced procedures, such as endotracheal intubation, to remain proficient with these skills. Cadaver labs, operating room time, and training mannequins have been used by prehospital agencies to address this shortfall. Continuing education often focuses on these less common, but critical, advanced procedures.

Integration of Prehospital and In-Hospital Systems

Prehospital care must be integrated closely into the regional trauma system. The distinction between the physician-based and paramedic-based system is not always clear. In the majority of the physician-based studies, physicians act as a supplement to the ordinary ambulances and work as a team on-scene with the paramedics and ambulance crews. An important factor for the overall success in caring for the prehospital trauma patient is the integration and working relationship between the physician and the paramedic. This integration can be the relationship of physicians working on-scene (as in the European system), or as part of on-line or off-line medical direction (as in the U.S.

model). Medical direction and oversight, which includes defining educational curriculum, supervising training, developing treatment protocols, and performing continuous quality improvement is a critical component in the organization of the prehospital system. The close cooperation between physicians and paramedics and knowledge of each other's needs and abilities is paramount to the success of integration between the prehospital and in-hospital phases of care.

Communication Between Hospitals and Field Units

Dispatch

Communication is essential throughout the trauma chain of survival. It starts with the patient or bystander alerting the EMS, often by phone via a standardized two- or three-digit number. The telephone number designated to activate an emergency response is different throughout the world, but there is a widespread use of two- or three-digit dedicated emergency telephone numbers, for example 911 in the United States, and 112 in European countries (though 999 is still used in some areas of the United Kingdom). However, numerous communities around the world still do not have a single emergency medical services telephone number. Furthermore, in major disasters telephone communication is often lost (e.g., Sept. 11, 2001, and Hurricane Katrina 2005) further contributing to chaos, and a delay in life-saving resources.

Dialing a dedicated three-digit number gives the caller access to a dispatcher who will send the appropriate emergency personnel as well as offer basic care instructions over the telephone until rescuers arrive. With current digital cellular and satellite phone systems, it is now possible to instantaneously identify the telephone number and location of the incoming call. However, not all metropolitan areas have this capacity as of this printing. As these capabilities develop, this technology will facilitate more accurate and rapid EMS dispatch. Similarly, satellite systems and global positioning systems make it possible to identify the location of the ambulances en route, increasing the efficiency of dispatching ambulances nearest to the scene.

On-Scene Communication

In the case of motor vehicle collision as well as mass casualty incidents, the police, fire services, and ambulances need to be able to communicate with each other on scene as well as with the hospital while en route. Communication with the hospital, whether direct or through a base station, is essential for triage of the patients and to enable hospitals to prepare for the inbound patients.

Mixed communication systems with telephone, radio, and computer integration are continuing to be developed, and as analog technology is replaced by digital technology, transmission of both voices and images is currently possible. Telemedicine (Volume 2, Chapter 72) has been used for the traditional transmission of electrocardiograms for cardiac patients, and to a minor extent, in trauma cases by photographs or videos from the scene. This can facilitate decisions at the dispatch center and can supply the trauma team with important information concerning the mechanism of injury and patient condition. The wide variation in organization and equipment used in communication stresses the importance of being familiar with the local communication system. Telemedicine (Volume 2, Chapter 72) will probably play an increasing role in the future development of prehospital care communication systems.

SYSTEM MANAGEMENT STRATEGIES

Overview of Management Strategies

The aim of any prehospital system is to provide optimal care until patient management is transferred to the hospital staff. This includes on-scene evaluation and triage (Volume 1, Chapter 4) as well as transport (Volume 1, Chapter 7). The optimal system of prehospital health care delivery depends upon the infrastructure development, prehospital staff training, transport times to the hospital, and the allowance of local policy for ambulance crews to bypass rural hospitals in preference for higher level trauma centers better able to provide the required resources (e.g., neurosurgery). The heterogeneity of these factors in the real world has contributed to the debate in defining "optimal care" delivered at the scene and during transport. Although there is a quite a range of care, much recent debate has taken extreme views embracing either "field stabilization" or "scoop and run."

The former strategy, (sometimes referred to as "stay and stabilize" or "stay and play") involves bringing the technology to the patient by delivering ALS at the scene, including: (*i*) securing the airway by endotracheal intubation using rapid sequence induction (RSI) techniques, (*ii*) decompressing the chest, (*iii*) establishing IV access, and (*iv*) beginning IV fluid resuscitation in hypovolemic patients. The aim of these time-intensive procedures is to stabilize the patient as much as necessary on-scene, and only once this is achieved is the patient transported to the hospital.

The opposing view has been termed "scoop and run" to describe a practice in which minimal treatment is delivered at the scene. This philosophy involves managing the patient and any life-threatening emergency in the ambulance while en route, (when scope of practice allows); or waiting until the patient reaches hospital to deliver definitive care. Generally, European countries have tended toward a "field stabilization" policy, whereas North American systems have been more closely aligned to a "scoop-and-run" philosophy. Many systems have now evolved to a "blended approach," with limited treatment provided on-scene before departure to hospital and with additional care being given en route, as possible or necessary. This may involve making sporadic stops by the roadside, to perform a procedure (e.g., chest tube placement), as may be required.

Several studies supporting both extremes have been published in the literature over the past two decades, and debate continues regarding the optimal approach (20–22). Proponents of field stabilization argue that a Primary Survey and procedures necessary to treat life-threatening injuries should be carried out on-scene. Proponents of "scoop and run" argue that the time interval from injury to definitive surgical care is the main determinant of outcome, and that the patient should be transported to the hospital as soon as possible. These "scoop and run" advocates believe that ALS should be administered en route rather than at the scene, although procedures performed in the back of a moving ambulance are limited by vehicle motion and available space.

It is unlikely that either extreme is the correct approach for all patients. Another factor that may have contributed to mixed results in clinical studies is the variety in pathophysiology involved in different countries. Studies that include prehospital patients with a higher incidence of penetrating injuries will tend to conclude that a "scoop-and-run" management style is better, as it will transport patients to surgeons more quickly to repair the focal site of injury and hemorrhage. On the other hand, studies that are comprised mostly of patients with blunt trauma will tend to support more of a "field stabilization" policy (23). **A balance between "scoop and run" and "field stabilization" must be determined for a given region, based upon transport distances, prehospital resources, and mechanisms of injury (blunt vs. penetrating trauma).** Examination of the causes of prehospital death, as well as other factors like transport times and patient demographics, allows a more evidence-based approach to unraveling the optimal strategies for prehospital care.

Prehospital Mortality Data Drives Resuscitation Priorities

Of deaths occurring by blunt trauma, approximately 25% occur immediately at the time of the primary injury, forming the "first peak" of deaths as described by Trunkey in his didactic "trimodal distribution" (24). These are usually catastrophic central nervous system (CNS) injuries or massive cardiovascular wounds that are non survivable. An additional 25% of patients will die before reaching hospital, the "second peak" in the trimodal distribution; these deaths are mostly a result of traumatic brain injury (TBI), but also include potentially treatable injuries such as airway obstruction, or tension pneumothorax. McCoy et al. (25–27) found that TBI (34%), uncontrolled systemic hemorrhage (25%) or both (8%) were the main causes of prehospital death, and other studies have reported similar results. Delays in initiating prehospital treatment have also been shown to be a contributing factor in the outcome (28). Although studies have focussed on the effect of prehospital care on outcome, the effect of prehospital management on long-term disability is often overlooked and is likely to be significant. Airway management continues to be the single aspect of prehospital care where improvements are most likely to decrease preventable deaths. Indeed, supporting the airway, breathing, and circulation (the traditional "ABCs" of life support) still reigns at the top of the trauma management hierarchy (see Volume 1, Chapter 8).

Organizational Influences on the System of Prehospital Care

Overview

Differences in the organization of prehospital care structure and providers (e.g., with or without physicians on scene) have contributed to the evolution of the so-called "field stabilization" against "scoop and run" concept of prehospital care, defined earlier. In Europe, physicians treat patients both on-scene and en route, but they also prioritize rapid transport. Similarly, paramedics in the United States not only expedite transport to the hospital but also initiate treatment of the patient while en route. It is not possible to give a simple answer as to which of these systems is best, as it is an integrated part of the whole socioeconomic, political, and organizational structure of the particular society. The epidemiology of injury having penetrating trauma, comprising a significant component in many regions of the United States, and parts of the population being concentrated in densely populated metropolitan areas with short transport times favors paramedic-based "scoop-and-run" systems. Conversely, the vast majority of blunt trauma in Europe occurs with an infrastructure of a more uniformly and less densely populated continental Europe, favoring the physician-based "field-stabilization" system. Moreover, the structure of some European hospital systems almost demands heavy reliance upon initiating resuscitative procedures in the field (i.e., the infrastructure of separate "specialty clinics" rather than an integrated general hospital).

Evidence for "Scoop and Run"

Proponents of "scoop and run" argue that prehospital treatment prolongs the time to definitive treatment. Several studies suggest that field treatment-associated delays in transport worsens the outcome, particularly in penetrating trauma. Studies from South Carolina showed that reduction in field times through adoption of a "scoop-and-run" policy for unstable and penetrating trauma reduced the number of patients who deteriorated en route to hospital, and ultimately doubled survival rates (29). In a small study, Gervin and Fischer retrospectively evaluated patients with penetrating cardiac injuries who were promptly transported with minimal prehospital therapy compared to those who had received prolonged attempts at stabilization in the field (30). Fifty-six percent ($n = 13$) were alive at the time of ambulance arrival, with systolic blood pressures greater than 90 mmHg. Approximately one half of the patients were treated with "scoop-and-run" technique with minimal in-field treatment, and the remaining patients were treated with extensive in-field attempts at stabilization. Patients managed by "scoop and run" with potentially salvageable injuries had a survival rate of 38%; in comparison, none of the patients who received field stabilization survived. Ivatury et al. (31) also found significantly improved survival in patients with penetrating thoracic injuries when they were treated by immediate transport rather than field stabilization.

Most studies showing the benefits of "scoop and run" have originated from the United States in urban areas, where a significant proportion of patients either have penetrating injuries, or require operative control of hemorrhage, or both. For reasons discussed earlier, prolonged field stabilization is an inappropriate strategy for these patients because time to surgical control of the hemorrhage is the most important factor in determining the outcome under these conditions.

Evidence for "Field Stabilization"

Proponents of field stabilization cite data showing that prehospital airway obstruction is common, and many patients with "survivable" injuries died due to obstructed airways. This association appears particularly common in patients with TBI, where hypoxia caused by airway obstruction or inability to achieve ventilation causes significant morbidity and mortality beyond that seen in patients who had no head injuries.

Several studies have shown that secondary brain injury is a common contributor to prehospital morbidity and mortality. Davis et al. (32) studied 100 TBI deaths in South Africa and judged hypoxic brain damage to be a contributing factor in 88% patients. More than 95% of patients with TBI are found to have ischemic CNS lesions at postmortem; many of these ischemic lesions occurred after the primary brain injury.

Doran (33) suggested that early endotracheal intubation of head-injured patients could reduce mortality and morbidity from hypoxia. It is not surprising that most clinical studies have confirmed this theory. Wang and Sweeney (34) undertook a retrospective study of mortality in 1092 blunt trauma patients with a Glasgow Coma Scale (GCS) score that was less than eight. Half had been treated by field stabilization, including securing of the airway by endotracheal intubation on scene; the others had been treated by the "scoop-and-run" method, with definitive airway management not being delivered until arrival in hospital. Of the 351 with isolated TBI, mortality was 23% for those intubated in the field, but rose to 50% in the group not intubated until arrival in hospital. The authors attributed this finding to improved oxygenation and ventilation, which minimized the secondary ischemic CNS damage. A less marked but significantly increased survival was seen in patients with combined TBI and injuries to other areas and in patients without TBI. Lockey et al. (35) showed that unconscious patients with TBI intubated in the prehospital setting have a 40% better chance of survival with good neurological outcome. Although most studies have focussed on mortality, there is little research into the corresponding effects of similar interventions on morbidity or quality of life (e.g., return to productivity) following prehospital endotracheal intubation.

Table 1 Prehospital Trauma Evaluation and Treatment Priorities

Prehospital ABCDEs	Explanation/description/comments
A—Airway	Basic and advanced airway maneuvers, surgical airway, administration of oxygen, use of sedative or paralytic medications to secure the airway (in certain jurisdictions)
B—Breathing	Needle decompression, tube thoracostomy
C—Circulation	Intravenous access, size and location of cannulae, volume and type of fluid administered, drugs given to support the circulation
D—Disability	Neurological state, spinal precautions, steroids
E—Extra info. and environmental protection[a]	Medications given, including pain management, other procedures performed (e.g., splinting, reductions). Protection of the patient from environmental extremes (e.g., excessive heat, cold, wind, etc.)

[a]The "E" used in the Advanced Trauma Life Support® (ATLS®) Primary Survey and Secondary Survey has a slightly different focus, representing "Exposure and Environmental Control" instead.

Optimum Mode of Transport

The optimum mode of transport depends upon where the patient is located. Ground ambulances are most appropriate for short runs in physically safe regions. Helicopters are favored for remote locations with uneven terrain, or limited landing area, or both. In addition, fixed-wing aircraft are best for long distance travel (provided runway capacity is available). Occasionally, helicopters are used to transport patients over short distances when urban traffic, geographic barriers, or armed conflict inhibits ground transport (see Volume 1, Chapters 4 and 7).

PREHOSPITAL MANAGEMENT PRIORITIES

Airway

Airway obstruction continues to be a major contributory factor in prehospital deaths. As in all stages of trauma care, the prehospital management priorities also begin with the ABCs (airway, breathing, circulation). In addition, evaluation for and protection from disability (D) is achieved, and extra (E) information is sought, while environmental (E) protection is assured (Table 1). In the Advanced Trauma Life Support® (ATLS®) scheme, the ABCDEs emphasized during the "Primary Survey" and "Secondary Survey" are the same as those used in the field, except for the component "E." In the field, "E" stands for "extra information" (e.g., procedures performed etc.) and environmental protection (e.g., protect the patient from extremes of heat or cold), whereas in ATLS, "E" stands for "Exposure and Environmental Control," meaning completely undress the patient, visualize all body surface areas, but prevent hypothermia (see Volume 1, Chapter 8).

As many as 85% of trauma patients who die of potentially preventable conditions before reaching the hospital do so because of airway problems (36). Airway obstruction is of particular significance in patients with TBI, as hypoxemia has been shown to specifically increase mortality. An Australian study estimated that 7% of deaths from motor vehicle accidents were on account of airway obstruction and subsequent asphyxia, without any other major injury (37). Similarly, the same U.K. study found that in 9% of deaths, patients had an injury severity score (ISS) less than 16, indicating a degree of primary injury that by itself would be unlikely to cause death. A study from Greece found that although 65% of trauma fatalities were associated with airway obstruction or tension pneumothorax, the figure rose to 74% in those with TBI, again showing the deleterious effect of hypoxia on head injury (35).

Airway management is particularly critical following TBI, cervical spine, or thoracic trauma and takes precedence over immediate transport unless it can be performed easily en route. Orotracheal intubation, either with or without sedatives and paralytics, is the mainstay for airway management for most prehospital systems employing a paramedic or higher level of rescuer or provider. Other airway adjuncts utilized in the field include bag-valve-mask (BVM) ventilation with jaw lift, use of an oral or nasal airway, esophago–tracheal-combitube (ETC), or laryngeal mask airway (LMA), nasotracheal intubation, and expedient "surgical airway" through percutaneous needle, or open cricothyrotomy. The emergency airway management methodology employed is often determined by the local "scope of practice" permitted, the experience and training of the individual provider, along with the various airway management tools and pharmacological adjuncts available.

Success rates for endotracheal intubation performed by paramedics in the field have been reported up to 98% with the use of neuromuscular blockade (NMB) drugs (38). Without the use of sedatives or paralytics, success rates decline substantially because of jaw clenching, gag reflexes, and patient combativeness (39,40). Intubation of severely injured patients is a complicated skill requiring both knowledge and experience (41). Depending on local policy and scope of practice, paramedics may or may not have access to sedative or paralytic medications to facilitate intubation in patients requiring airway protection or ventilatory support. When protocols are prohibitive of these procedures, intubation success rates in patients with higher GCS scores are often lower than in flaccid unresponsive patients with lower GCS scores and dismal rates of meaningful survival (42).

Physicians providing airway management in the prehospital setting have generally been shown to be skilled at endotracheal intubation. A prospective, descriptive, consecutive prehospital study of emergency intubation by French physicians showed an intubation success rate of 99.1% (43). The majority of the general trauma patients and TBI patients had sedation (including ketamine, etomidate, midazolam, or propofol). In contrast, a new study of paramedic success in a large U.S. city demonstrated only 88% success rate with 9% esophageal intubation (44). Once an airway has been maintained or established, attention moves toward ventilatory management, or breathing.

Breathing

In the awake, cooperative, spontaneously breathing patient with a stable airway, little needs to be done beyond the application of oxygen by facemask, followed by continuous monitoring of airway and ventilation. Pulse oximetry is currently the "standard of care" for measuring oxygen hemoglobin saturation levels in prehospital patients. In the intubated patient, ventilatory status can be further characterized by end-tidal carbon dioxide ($P_{ET}CO_2$) monitoring. In the nonintubated, $P_{ET}CO_2$ can be used as a qualitative measure on ongoing ventilation only. Colorimetric, qualitative measuring devices, such as those provided by Nellcor-Puritan Bennet (Pleasanton, California, U.S.A.), allow the provider to confirm endotracheal positioning of the tube by detecting exhaled CO_2. For situations with longer transport times, quantitative $P_{ET}CO_2$ monitoring allows the provider to follow $P_{ET}CO_2$ levels throughout the transport. Furthermore, with proper training in interpretation of $P_{ET}CO_2$ physiology (including waveform morphology), one can incorporate this data while adjusting ventilation, fluids, and drugs during resuscitation and transport. The use of $P_{ET}CO_2$ is most efficacious when intermittent arterial blood gas (ABG) samples are available. In the near future, it is anticipated that bedside ABG capability will be applied more widely to the prehospital setting.

The initiation of positive pressure ventilation can induce or exacerbate a tension pneumothorax. Identification and management of a tension pneumothorax requires specific training. Both missed diagnosis and inadequate chest decompression can result in morbidity and mortality from a tension pneumothorax (28,45). Along with hemothorax and flail chest, pneumothorax remains a significant cause of prehospital death. In a study of 231 prehospital deaths caused by penetrating trauma, 19% of deaths likely resulted from an isolated lung wound causing either a tension pneumothorax or hemothorax (46). Most of these cases were assessed as being survivable if early appropriate treatment had been employed. In blunt trauma, tension pneumothorax is less common. Similarly, an Australian study showed that tension pneumothorax accounted for 4% of avoidable prehospital blunt trauma deaths following motor vehicle accidents (47).

The extent of treatment for this condition varies based on the local "scope of practice" (Volume 1, Chapter 25). Needle thoracostomy is a skill that is taught to paramedics and is the first line treatment for suspected tension pneumothorax. Many systems utilizing flight nurses or prehospital physicians will place a chest tube as the initial procedure. Whenever a needle thoracostomy has been used to decompress a tension pneumothorax, follow-up with a formal tube thoracostomy is required. In one study, field use of tube thoracostomy by physicians was shown to be highly successful without any of the 63 patients developing pleural infections during the course of hospitalization (48).

Circulation

Of all areas of prehospital care, circulatory management and support for hypovolemic trauma patients is probably the most contentious. The original ATLS guidelines recommended insertion of two large-bore cannulae and administration of sufficient IV fluid to restore circulating volume to a normovolemic state (normally beginning with 2 L of balanced crystalloid solution). Although systems utilizing the field-stabilization model aim to initiate fluid resuscitation before transport, very little fluid is typically given in the prehospital phase. Indeed, in a recent study, mean prehospital infusion rates ranged between 17 and 47 mL/min, with mean prehospital total volumes infused being only 500 mL (49). The time spent on-scene initiating IV infusions has been shown to delay transport to hospitals in some systems, yet has been fairly negligible in others (49–53). **Controversy still exists over the quantity, type, and timing of IV fluid administration for hypotensive trauma patients.**

A clearer understanding of the pathophysiological mechanisms involved in hypovolemia has moved this strategy toward one of limited fluid resuscitation ("delayed resuscitation"), a concept known as "permissive hypotension." This has resulted from both animal and clinical studies showing that in an uncontrolled hemorrhage, aggressive fluid resuscitation increases blood pressure, and this increase in pressure simultaneously dilutes coagulation factors and dislodges blood clots, combining to accelerate the rate of blood loss (54–56). Accelerated bleeding will necessitate further administration of IV fluids, resulting in a dilutional coagulopathy, progressive hypothermia, and a "vicious circle" ensues, which continues to worsen the patient's status. Once hemostasis has been achieved, usually through surgical intervention, normovolemia can be restored with fewer iatrogenic complications.

The benefits of delaying IV fluid resuscitation were first described during World War I, when Cannon suggested that "hemorrhage in the case of shock may not have occurred ... because blood pressure has been too low ... to overcome the obstacle offered by a clot. If pressure is raised before the surgeon is ready, blood that is sorely needed may be lost" (57). This lesson has been rediscovered over the past decade, initially with animal studies and then in clinical trials. Animal models of uncontrolled hemorrhage have repeatedly shown that attempts to restore circulating blood volume to "normal" (without controlling the source of bleeding) results in increased mortality through accelerated blood loss, reflecting that a strategy of "permissive hypotension" can be an optimal management strategy preceding hemorrhage control. Kowalenko et al. (58) showed that aggressive saline infusion increased blood loss and failed to improve survival in swine with uncontrolled hemorrhage. Similarly, Krausz et al. (59) found that resuscitating hypotensive rats with 0.9% saline resulted in more bleeding and hemodynamic instability than in those with no treatment; a policy akin to "scoop and run."

In what is regarded to some extent as a seminal clinical study, Bickell et al. (56) reported on 598 trauma patients randomized to receive either delayed fluid resuscitation or immediate fluid resuscitation prior to surgery. The group subjected to immediate resuscitation had a statistically significant reduced survival (63% vs. 70%) as well as a greater complication rate from acute respiratory distress syndrome (30% vs. 23%). The overall complication rate was lower and hospital stay shorter in the delayed-fluid administration group. A better outcome has also been produced by delaying IV fluid resuscitation until operative control of bleeding from major abdominal trauma has been achieved (60). Several other studies have failed to show, at best, any significant benefit from prehospital IV fluids. Cayten et al. (49) studied the relation of prehospital fluids to outcome in 199 trauma patients, and Kaweski et al. (61) repeated the study with 6855 trauma patients; both find no benefit from administration of prehospital IV fluids.

Computer modeling of IV fluid administration in patients with traumatic hemorrhage concluded that IV fluids were only of benefit if prehospital time was greater than 30 minutes, the bleeding rate was between 25 and 100 mL/min, and the infusion rate was at least equal to the bleeding rate (62). These three criteria are rarely met in urban trauma environments, but may be appropriate in rural areas with long transport times or in patients requiring prolonged extrication (see Volume 1, Chapter 11, for further discussion on fluid management).

Establishing IV access remains a basic and essential skill of the prehospital provider for trauma patients. Typically placed en route in North American systems (to minimize total on-scene time), IV access allows for fluid treatment of clinically significant hypotension, medication administration, and earlier access for transfusion upon arrival to the hospital. Techniques utilized in the prehospital setting include peripheral IV access, central venous access, and intraosseus access. Paramedics are trained in peripheral and intraosseus access, while nurses and physicians are typically trained to perform all three in the field (see Volume 1, Chapter 10, for additional discussion of IV access for trauma). Finally, once patients are stabilized, most trauma units practice routine replacement of all "potentially contaminated" IV catheters that were placed in the field; optimally catheter replacement occurs within 12 to 24 hours of hospital arrival (to decrease the risk of line sepsis).

COMMUNICATION OF PATIENT INFORMATION TO THE TRAUMA TEAM

Prearrival Report

All prehospital providers involved in the management of patients with major trauma must be able to communicate efficiently and accurately with the receiving hospital. This allows the receiving hospital to assemble all necessary staff and brief the trauma team with prehospital data that will facilitate assessment and management upon patient arrival. In some cases, it will also allow the operating room (OR) staff to be prepared, or in the case of major multicasualty incidents, suspension of the elective surgery schedule until OR requirements are known. Prehospital reports are particularly important in incidents involving hazardous materials, as additional measures may be necessary to prevent contamination of the hospital and its staff.

In some systems, communication is achieved by passing the information from the field provider to an ambulance dispatch center or radio room, which then relays the information to the receiving hospital. This has the obvious disadvantage that the message may become accidentally corrupted during relay, with the hospital being given erroneous information. A more efficient route is for the information to be given directly to the receiving hospital by the ambulance crew. However, a systematic method of information transmission is required to ensure that concise and consistent data are sent and that essential information is not omitted. Similarly, the receiving system for incoming information must be standardized to avoid distractions from content and to minimize situations in which no one is listening to the report.

Long, detailed prearrival reports may take the focus away from patient care. Thus, brief but thorough reports are preferred. **A prearrival report needs to be succinct but complete. Formats for reporting the necessary information are important, such as the mechanism-injuries-vital signs-treatment (MIVT) approach, which is a concise way of reporting the key elements to the trauma team.** The prearrival report is usually more concise than that given on arrival at the hospital, but should include the necessary information outlined in Table 2. This information can usually be transmitted in the form of a several-sentence narrative. Additionally, the estimated time to arrival should be given. The person receiving the information should then read it back to ensure correct reception of the information.

The ambulance radio system is often used to transmit information, but requires the receiving hospital operator to be familiar with radio procedures and the use of the equipment. With improving coverage of mobile telephone networks, cellular technology is often an alternative route for transmitting information. Analog radio and mobile telephones

Table 2 Prehospital Report: Mechanism–Injuries–Vital Signs–Treatment Format

MIVT report category	Decision-making elements
(M) Mechanism	How did injury occur?
	Presence of drugs or alcohol
	Deaths at scene
	Confounding issues
(I) Injuries	Primary survey
	Glasgow Coma Scale
	Level of consciousness
(V) Vital signs	Heart rate
	Blood pressure
	Respiratory rate
	Oxygen saturation
	Temperature (if applicable)
(T) Treatment	*Airway* (airway management)
	Breathing (oxygen administration, needle or tube thoracostomy)
	Circulation (intravenous access established and fluids administered)
	Disability—neurologic (spine precautions)
	Extra information (medications administered, procedures performed)

do not provide a secure route for the transmission of voice data; however, newer technology offers digital encoding, which will limit eavesdropping on conversations.

Advances in telemedicine (Volume 2, Chapter 72) now enable transmission of physiological data to the receiving hospital prior to arrival. Transmission of video data from the scene is developing and is only limited by the rate of data transmission (bandwidth) and the creativity of the first responders and the video data engineers.

Transfer of Care and Patient Information

A comprehensive (detailed but concise) handover is important in providing the trauma team with an understanding of the time and mechanism of injury, actual or suspected injuries, clinical condition of the patient, and treatment given. The patient "handover" is a bit more detailed than the prearrival "MIVT" report (Table 2), and offers the opportunity to update the trauma team on any changes that might have occurred since the initial report was given. The "handover" report should be initiated by notifying the trauma team of the approximate age and sex of the patient even though this information is usually apparent.

Mechanism

Following the initial information, the mechanism of injury (Volume 1, Chapter 2) and the approximate time of the injury should be reported. An understanding of the mechanisms involved in creating the injury enables the trauma team to focus on probable injuries. This is particularly true for injuries sustained during blunt trauma, such as motor vehicle crashes. A patient retrieved from a vehicle involved in a frontal impact may have deceleration injuries, such as maxillofacial trauma with cervical spine injury, or thoracic injury, or both, such as myocardial contusion or partial aortic disruption. A patient in a car hit from the right side may have a pattern of right-sided chest injuries, liver injury, and right-sided limb fractures. An estimate of the speed of the vehicles upon impact will give some indication of the amount of energy transferred. The use of safety devices such as seat belts, air bags, and motorcycle helmets are also important in determining risk for specific injuries. Some agencies utilize digital photographs taken at the scene of a motor vehicle crash to better illustrate this information for the trauma team.

The time of the injury is important in assessing the rate of deterioration of the patient. If the patient has been trapped for several hours, but remains hemodynamically stable without circulatory support, the tempo of the evaluation of the patient would differ than if the patient has had a rapid deterioration in blood pressure over 15 to 20 minutes. Prolonged scene times in colder environments are likely to result in significant hypothermia, so it is important to describe environmental conditions and the duration of exposure (63).

Injuries

Although it is not possible to conduct a complete evaluation of the patient in the field, details of suspected injuries will enable the trauma team to focus on appropriate management. The prehospital provider should complete a primary survey and report positive findings. Included in this portion of the report would be a comment on the status of the airway, thoracic and abdominal examination, spinal issues, obvious extremity deformities, and GCS.

Vital Signs

The vital signs are reported and should include the heart rate, blood pressure, respiratory rate, pulse oximetry readings and GCS score. Temperature should always be reported, especially when there is prolonged environmental exposure in a cold (or hot) location. This will enable the trauma team to more readily prepare a variety of warming (or cooling) measures for use immediately on the patient's arrival.

Treatment

Details of treatment given prior to arrival at the hospital help convey the clinical condition of the patient, and details of pharmacological therapy administered allows for more appropriate selection of subsequent drug therapy. A description of the treatment priorities (ABCDEs) in the prehospital phase was provided earlier (Table 1). Other patient details, including allergies, current medications, past medical history, and time of last oral intake should also be transmitted if known.

TRAUMA CENTER AND TRAUMA SYSTEM CONCEPTS

Background

The recognition by the U.S. National Academy of Sciences (64) that severe trauma constituted "the neglected disease of modern society" during the mid-1960s initiated the process of integrated trauma systems that continues to evolve today. The American College of Surgeons (ACS) considered trauma as a "surgical disease," and the first edition of their guidelines published in 1976 focussed on establishing the optimal hospital resources for treatment of severely injured patients. The initial classification of hospitals as trauma centers of differing levels, according to the available resources, was first defined in this publication. Since then, the focus has shifted toward integrating the various levels of trauma centers into a coordinated system of care. The more recent ACS guidelines for care of the injured patient: *Resources for Optimal Care in Injured Patients* reflects this emphasis (65).

Defining Trauma Centers and Systems

The "trauma system" is a network of definitive care facilities providing the complete "spectrum of care" for all injured patients. The ideal trauma system takes care of every injured patient and contains all components including: prevention, prehospital care, acute care, surgery, intensive care, and rehabilitation. **The goal of the trauma system is to match the needs of an injured patient to the resources of the available facilities so that optimal and cost-effective care is achieved.**

The ACS-Committee on Trauma (COT) defined trauma-center classifications from levels I–IV, based upon the degree of available resources (Table 3). Furthermore, a system for enabling continuous performance improvements (including trauma registry and audit of morbidity and mortality) as well as continuing education, research, and prevention programs are all considered necessary. **The ACS-COT Trauma System designations are classified in a system that is numerically the opposite of the "levels or "echelons" of care used by the U.S. military (and other NATO countries).** Indeed, the ACS-COT Trauma System designation signifies level I centers as those with the highest capabilities and the greatest level of resources. The military levels of care (previously referred to as echelons),

Table 3 Trauma Center Level Designations, Role Within Trauma System, Staffing and Volume Requirements, and Contrast with U.S. Military "Levels of Care"

Category	Relative designation (more resources available to the right)				
ACS-COT Trauma Center	Level V	Level IV	Level III	Level II	Level I
Role within a coordinated trauma system	Not formally recognized by the ACS[a]	Provides ATLS® (resusc. and stabilization) then transfer to nearest appropriate-level trauma center	Provides prompt assessment, resusc., emergency surgery, and stabilization with transfer to a level I or II as appropriate	Initial management capabilities generally similar to level I, but often located in less population-dense locations	Regional resource. Full capability of management from prevention to rehab., including research
Immediate 24 hrs staffing requirements	None	No specific in-house MD req. In-house nurses and resuscitation equipment	Trauma surgeon and anesthesiologist must be avail $\leq$20 min. No req. for neurosurgical coverage In-house nurses and resuscitation equipment	Trauma surgeons and neurosurgeons can be out of house but avail. $\leq$20 min. Anesthesiologists "must be in the OR by the time the patient arrives" In-house nurses and resuscitation equipment	In-house trauma surgeons, anesthesiologists, and physician specialists (e.g., neurosurgeons, and orthopedic surgeons), nurses, and resuscitation equipment. Includes pediatric cases
Volume and experience requirements	None	None	None	Same criteria as level I except volume standards and research are not required	1200 admissions a year or 240 major trauma patients per year, or an average of 35 major trauma patients per surgeon
U.S. military Level of Care[b]	I	II	III	IV	V
U.S. military examples	Buddy aide, self-aid	FST MFST CRTS	CSH EMEDS + 25 Fleet Hospital	Landstuhl Army Regional Medical Center, Germany	Walter Reed Brooke Army
Resources	Minimal	Limited surgical and medical capabilities (100% mobile)	Highest level of care available within the combat zone	Definitive surgical and medical services outside the combat zone, but is in communication zone of the TO	Ultimate treatment capability for patients generated within the TO. Provides maximum return to function
Surgical capability	None	Emergency surgery only	Surgery and critical care capabilities	Full range, but limited stay until can transport	Full range, available 24 hrs a day

[a]Some states use the Level-V Trauma Center designation to further categorize hospitals providing life support only prior to transfer.
[b]"Level of Care" was previously referred to as "Echelons of Care" by NATO countries.
Abbreviations: ACS-COT, American College of Surgeons-Committee on Trauma; ATLS®, Advanced Trauma Life Support®; CRTS, casualty receiving and treatment ships (Navy); CSH, combat support hospital (U.S. Army and Marines); EMEDS + 25, expeditionary medical support (25 bed version—U.S. Air Force); Fleet Hospital, 500-beds (80 ICU beds), 6 ORs (U.S. Navy); FST, forward surgical team (U.S. Army); MD, medical doctor; MFST, mobile field surgical team (U.S. Air Force); Rehab., rehabilitation; Resusc., resuscitation; req., requirement; equip, equipment; TO, theater of operations.

however, designate level I (no surgical capability) care as the most rudimentary and level V as the highest level of care possessing the greatest resources (see Volume 1, Chapter 5, for further discussion of the levels of care).

The level-I trauma center is a regional resource, serving as a tertiary care facility and having the capability of providing total care for every aspect of injury, from prevention to rehabilitation. A list of the resources that

Table 4 American College of Surgeons Required Available Resources for Level I Trauma Center

Requirement	Details and comments
24-hr in-house availability of attendings	Surgeon attending (PGY four or five residents may begin resuscitation while awaiting attending, but is not considered replacement of attending surgeons)
	Anesthesiologist attending (chief residents or CRNAs may be used to provide emergency airway management and initiate surgical anesthesia, but the anesthesiologist attending must be available at all times and present for all operations)
	Emergency medicine attending (only if emergency medicine specialists are involved with the care of trauma patients)
Immediate availability (24 hr/day) of surgical sub-specialists and critical care	Neurosurgery (dedicated to one hospital or have back-up system)
	Orthopedic surgery (dedicated to one hospital or have back-up system)
	Microvascular/replant surgery
	Others (critical care medicine, cardiac surgery, hand surgery, plastic surgery, oral/max-face, ophthalmology, thoracic surgery, OB/gyn) must be available for call-in 24 hrs a day:
Specific patient care areas and services must be designated "available 24 hr/day"	OR
	PACU
	ICU
	Resuscitation suite (adjoining trauma ICU, or ED)
	Radiological services (must be available 24 hrs/day, Attending must review all preliminary films and report final findings within 24 hrs)
	Clinical laboratory services
	Respiratory therapy
	Acute hemodialysis
	Burn care (in-house or transfer agreement)
	Acute spinal care management (in-house or transfer agreement)
Other services required (on less urgent basis)	Rehabilitation services
	Morbidity and mortality review
	Prehospital trauma care review
	Transfer review (times and reasons)
	Trauma bypass review (times and reasons)
	Trauma multidisciplinary review
	Research
	Injury control studies
	Prevention programs and monitoring

Abbreviations: ACS, American College of Surgeons; CRNAs, certified registered nurse anesthetists; ED, emergency department; ICU, intensive care unit; OB/gyn, obstetrics and gynecology; OR, operating room; PACU, post anesthesia care unit.

are required to be available at level-I trauma center are summarized in Table 4. Generally, level-I trauma centers serve large cities or densely populated areas and are expected to manage a large number of injured patients with a minimum severity of injury. According to the most recent guidelines, they are expected to admit at least 1200 trauma patients yearly; or 240 patients per year with an ISS of greater than 15; or an average of 35 patients with ISS greater than 15 per surgeon per year (65).

These requirements concerning volume as well as some components of research productivity, publications, and community outreach separate the level I center from the level II center. Level II centers are most often placed in less densely populated areas. The trauma centers located within a specific region work together to optimize the care, depending upon the clinical capabilities and the needs of the patients. The specific interactions vary by state and by counties within the state.

The level-III trauma centers are capable of providing resuscitation, emergency operations, and stabilization. Transfer agreements with higher-level trauma centers facilitate specialized and definitive care of the most severely injured. Level-III trauma centers are usually located in rural areas. Level-IV trauma centers are generally located in remote areas and provide initial advanced life support and arrange for transport to higher-level centers for further care. The ACS-COT does not recognize the designation level-V trauma center, but some states use this terminology to further designate hospitals that provide "initial resuscitation only" prior to transport to higher-level facilities.

Within the trauma regions, the trauma centers of different levels ideally form a network ensuring that the patients receive optimal treatment in the most resource-effective way. Additionally, cooperation is expected between the centers, and the development of formal "transfer agreements," describing all of the legal, economic, and medical aspects of the relationship are encouraged. Ideally, the entire trauma system in a region or state should be designed on the basis of need and existing resources, with all affected parties involved in the planning, development, and implementation. Furthermore, the governing nation should have medical-necessity transit agreements between states and neighboring countries to avoid treatment delays.

A prerequisite for the trauma system with centers of different levels is appropriate triage. Triage criteria defining specifically those patients that should primarily be transferred to a level-I trauma center are included in the ACS-COT guidelines. Triage criteria can be defined according to local needs, although the essential issue is that they have been defined, accepted, and implemented (see Volume 1, Chapter 4). Previous work has commented that only a small percentage of all injuries are significant enough to justify triage to the higher level trauma centers; thus, triage is critical in balancing patient flow within a busy system (66).

Effectiveness of Trauma Centers and Trauma Systems

Many studies have been published purporting the success of trauma systems in reducing preventable death (67–71). However, much of the research is retrospective in nature, and does not control for potential confounding factors. The ACS-COT sought to use evidence-based scientific methods to support their recommendations for trauma centers and the components for trauma systems; however, the quality research they sought is challenging, if not impossible to produce, and is thus lacking. In recognition of the problem of evaluating trauma systems with an evidence-based approach, the Skamania Symposium (72) was held in 1998 to critically evaluate the effectiveness of trauma systems. The literature in the review was limited to English language and to trauma systems in the United States and Canada.

The research within trauma systems is based upon: (*i*) panel studies, (*ii*) comparisons of registries from trauma centers, and (*iii*) population-based research. In the systematic review, a total of 12, 11, and 17 of these study types were included, respectively. The panel studies were classified as class III evidence, but provided some support for designated trauma centers being more effective in terms of fewer preventable deaths among the seriously injured and less inappropriate care (73,74). The research on trauma registry comparisons founded on TRISS-scoring showed that there was a 15% to 20% reduction in the risk of death comparing trauma system outcomes to the MTOS (75). A population-based studies likewise found a 15% to 20% improved survival among seriously injured patients with the implementation of a trauma system (76). Finally, a recent study published in the New England Journal of Medicine has added further evidence to the impact of centralization to patient outcome (77).

The primary indicator measured in the existing trauma center studies was hospital death. Future research should include measurements of the total "spectrum of care," from prehospital to rehabilitation and include measurements other than mortality, such as morbidity and long-term quality of life. Overall, there is a large body of research reporting decreased mortality with the implementation and utilization of trauma systems, but more rigorous research is still needed in this arena.

EYE TO THE FUTURE

Prehospital care is in its relative infancy compared with other fields of medicine. Indeed, prior to the 1960s, few cities had organized EMS services. Regions with less structured and organized systems have the greatest potential for improving arrival and transport times of the injured patient. More organized systems need to investigate how further reducing their transport times, (and at what additional costs) most optimizes patient care.

Access to well-organized dispatch system is essential to the appropriate and effective use of EMS-resources in order to dispatch the necessary and appropriate resources to the right patient. Trauma triage criteria and transport destination indications are diverse from system to system, without much data to support decisions regarding selection of specific criteria. Research is needed in this area to determine the best use of prehospital resources, while maintaining optimal patient care, and not presenting a community with an unjustifiable economic burden.

Communication between the field providers and the "in-hospital" trauma teams is expected to improve with the use of emerging telecommunication technology for monitoring, medical oversight, and (potentially) triage decisions. These technologies can also serve to visually prepare the trauma team for the patient's arrival with digital images of the scene, the patient, and the relevant vital sign data during transport. Research will also be required to ensure that this expensive equipment is used optimally to improve patient care rather than to merely create more time-consuming activities at the scene (see Volume 2, Chapter 72).

Optimal management of severely injured patients, both in and out of the hospital, continues to evolve. Only in recent times has prehospital airway management in many systems progressed from primarily nasal intubations to the use of rapid sequence intubation (RSI) and, more recently, veered away from aggressive hyperventilation of intubated prehospital patients with acute head injuries (78–80). Some areas for future consideration involve the development of algorithms for field intubations that include airway options traditionally available only in the hospital [e.g., fiberoptic intubation (FOB) of a patient trapped in a motor vehicle wreck without adequate access for conventional intubation, etc.]. Questions to ponder include: (*i*) Should specialized "intubation teams" be established to manage airways, using advanced techniques like FOB for spinal cord injured and obese patients? (*ii*) Should the pendulum swing from "deliberate hyperventilation" all the way to "permissive hypercapnea" in a subset of injured patients without TBI?

While the debate on the benefits and detriments of prehospital fluid resuscitation continues (42,81–83), additional prospective RCTs evaluating alternative fluid therapies (such as hypertonic saline or artificial blood products) will generate data to better answer questions regarding the optimum type, quantity, and timing of prehospital fluid administration.

The administration of steroids for spinal cord injury victims in the prehospital setting has been used in some systems for years. However, given recent debate by neurosurgeons as to whether this represents the optimal treatment, the appropriate dosing, or if there are significant complications that arise from their use, the debate has evolved to include the prehospital arena (83–87). Future work in this area will determine whether systems already utilizing steroids in the field will continue, while other studies will determine if other drugs should be initiated in the prehospital setting. The future in prehospital management of trauma victims will also depend upon prospective RCTs evaluating the optimum forms of cardiovascular support. As the management of trauma patients has so many involved components, large multicenter trials will be required to better define outcomes.

International and evidence-based guidelines need to be investigated and published within trauma care as they successfully have been within advanced cardiac life support in an international cooperation.

Prehospital providers have also been actively involved with injury prevention and will continue to work in this area. From seatbelts and airbags to helmet laws and firearm safety locks, injury prevention has always been a banner carried by prehospital providers (89–92). Injury prevention with well-designed trials to measure impact, in addition to prospective RCTs to evaluate management strategies in prehospital trauma care, constitutes a continued challenge. This is a rapidly changing area of care.

One major obstacle to prehospital data generation has been the lack of active involvement of physicians in the field in many locations. The dearth of clinically experienced principal investigators and the consequent difficulty in instituting carefully controlled trials has hampered prehospital research efforts. Another example of this problem is the inability to institute protocols calling for prehospital drug administration, requiring the participation (or physical presence) of a physician. Therapeutic advances and some research results have already probably been impacted, and potentially led to erroneous conclusions. For example, therapy for spinal cord injury and TBI may only provide benefit if applied within a therapeutic window that involves the prehospital time period (e.g., steroids, antioxidants, hypothermia, etc.).

SUMMARY

Although executed using a number of various approaches, all prehospital systems worldwide set out to extricate, initiate treatment, and rapidly transport the critically injured patient to a trauma center. "Scoop and run" and "field stabilization" represent extremes of prehospital management strategies for major trauma. Understanding the optimal approach has been clouded by studies supporting both strategies and is undermined by sociopolitical issues, such as the structure of the medical profession and protectionist strategies imposed by some labor unions. In reality, a balance between "scoop and run" and "field stabilization" must be determined for a given region based on transport distances, prehospital resources, and mechanisms of injury. For some regions, increased utilization of advanced procedures may be more appropriate, particularly based on the area's predominant mechanisms of injury, long transport times to a trauma center, and when there is a high training level of the EMS providers. Whether procedures are done at the scene or en route are also best determined by local conditions, transport modality, and provider capabilities.

Major trauma constitutes a spectrum of pathophysiology. Many patients who are unconscious, and particularly patients with head injury, are at risk for increased morbidity or mortality from hypoxia caused by airway obstruction. Impaired ventilation caused by tension pneumothorax is also a condition that requires immediate correction upon diagnosis. Patients whose injuries result in hemorrhage, more common in penetrating trauma, appear not to benefit from attempts to stabilize the circulation in the field. Initiation of vascular access prior to transport increases scene time; the role of IV fluids, (although controversial), may be detrimental to some patients through pressure-related augmentation of bleeding, clot disruption, hypothermia, and dilutional coagulopathy. These patients are best treated by a policy more akin to "scoop and run," since surgical hemostasis is the critical intervention, with time being of the essence. In general, if unstable, the patient's airway and breathing must be secured on-scene, and control of the circulation can be initiated en route with definitive treatment occurring at the trauma hospital.

Communication between the prehospital care providers and the trauma teams, (both on-line and off-line) are paramount to strengthening the trauma system. The providers must be able to communicate succinctly and completely with the trauma team, both in the field prearrival (MIVT) report and during patient turnover, so that critical elements of information are transferred.

Improvements in training prehospital providers continues to be a priority. Just as ATLS is taught around the world, prehospital trauma life support® (PHTLS®) is beginning to be taught globally as well. Although first taught in 1983, the handbook for PHTLS is now in its fifth edition (93), and stresses early recognition of life-threatening conditions in the field, application of key field interventions, and prompt transport to the closest appropriate facility (94).

The future of prehospital trauma care will follow the paths created by evidence-based research. Airway management, volume resuscitation, and medication treatment strategies are likely to evolve based on both laboratory and in-hospital clinical research and then be validated in prehospital trials. Even changes in system design, to improve arrival and transport times of patients, will require study and validation before finances are allotted for changing configurations. Prehospital treatment of the trauma patient is a rapidly evolving field and will probably change significantly over the next decade compared with the systems currently in place (94).

KEY POINTS

- Medical oversight of prehospital care runs the gamut from required physician presence at the scene, to protocols requiring real-time physician input through telecommunication, to merely retrospective involvement (e.g., follow-up quality assurance performance reviews).
- Prehospital levels of staffing, whether using paramedics or physicians, are dictated by local need and financial feasibility.
- Prehospital care must be integrated closely into the regional trauma system.
- A balance between "scoop and run" and "field stabilization" must be determined for a given region, based upon transport distances, prehospital resources, and mechanisms of injury (blunt vs. penetrating trauma).
- Proponents of "scoop and run" argue that prehospital treatment prolongs the time to definitive treatment.
- Proponents of field stabilization cite data showing that prehospital airway obstruction is common, and many patients with "survivable" injuries died due to obstructed airways.
- Airway obstruction continues to be a major contributory factor in prehospital deaths.
- Airway management is particularly critical following TBI, cervical spine, or thoracic trauma and takes precedence over immediate transport unless it can be performed easily en route.
- Controversy still exists over the quantity, type, and timing of IV fluid administration for hypotensive trauma patients.
- All prehospital providers involved in the management of patients with major trauma must be able to communicate efficiently and accurately with the receiving hospital.

- A prearrival report needs to be succinct but complete. Formats for reporting the necessary information are important, such as the mechanism-injuries-vital signs-treatment (MIVT) approach, which is a concise way of reporting the key elements to the trauma team.
- A comprehensive (detailed but concise) handover is important in providing the trauma team with an understanding of the time and mechanism of injury, actual or suspected injuries, clinical condition of the patient, and treatment given.
- The goal of the trauma system is to match the needs of an injured patient to the resources of the available facilities so that optimal and cost-effective care is achieved.
- The ACS-COT Trauma System designations are classified in a system that is numerically the opposite of the "levels or "echelons" of care used by the U.S. military (and other NATO countries).
- The level-I trauma center is a regional resource, serving as a tertiary care facility and having the capability of providing total care for every aspect of injury, from prevention to rehabilitation.
- Prehospital care is in its relative infancy compared with other fields of medicine. Indeed, prior to the 1960s, few cities had organized EMS services.

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4

Trauma Scoring and Triage

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INTRODUCTION

In acute diseases it is not quite safe to prognosticate either death or recovery.

—Hippocrates

Despite the above admonishment from Hippocrates, traumatologists have been developing scoring and triage methodologies for several decades. Indeed, quantifying severity of injury and optimizing triage decisions are integral to ensuring that the highest level of care is provided for the greatest number of patients. Scoring systems have been developed to describe the severity of injuries, as well as the general underlying condition. The purpose of triage is to sort the acutely injured by priority for treatment and transport and to make best use of available resources.

Trauma scoring and triage methodologies are based on statistical probabilities of survival. However, these systems have significant limitations when applied to the individual patient. The chosen methods of scoring and triage, combined with the abilities and experiences of the rescue personnel, and the capabilities of the trauma system itself, impact ultimate patient survival and outcome. Data are now being compiled in various trauma registries with the overall goal of categorizing the outcome for patients with similar degrees of injury. This data can then serve to benchmark the quality of care provided to patients with similar degrees of injury or illness.

The first five sections in this chapter review the current and most frequently applied methodologies of trauma scoring, including their practical application as quality assessment tools, and the use of various scoring systems in trauma registries. The second half of this chapter focuses on triage including definitions, applications, and limitations. Special situations where triage is most important are also specifically described. The chapter concludes with a brief review of future developments anticipated to occur in the fields of trauma scoring and triage.

TRAUMA SCORING DEFINITION AND CATEGORIZATION

Trauma scoring was introduced just over 30 years ago, when the automobile insurance industry and trauma physicians simultaneously created methods of assigning numeric values to describe the anatomical, physiological, and other consequences of injury. The aim of both groups was to reduce morbidity and mortality through the process of quality improvement. **Trauma scoring is a useful tool for: (*i*) triage and prehospital treatment, (*ii*) documentation using common terminology, (*iii*) injury severity description, (*iv*) quality of care and patient outcome evaluation, (*v*) trauma system evaluation and comparison, (*vi*) trauma epidemiology, research, and funding.**

A model is created when a trauma score is used to predict or correlate with an outcome measure. Models enable predictions and comparisons between patient groups or trauma systems (1). A simple scoring is adequate for urgent triage-level decision-making. However, the complex consequences of trauma are best described using scoring systems and prediction models combining anatomical and physiological parameters, along with age and comorbidity. Statistical models must be employed to enable data comparison.

Some of the numerous scoring systems that have evolved over the past 30 years are summarized in Table 1. Numerical values derived from trauma scores range from a few direct physiological parameters to multiple statistically calculated values—and must be applied accordingly (1).

Numerous well-functioning scoring systems are in use regionally around the world. However, a universal scoring and triage system has yet to be endorsed by all jurisdictions. Most currently employed systems score on the basis of anatomical injury, physiological impairment, or combinations thereof.

Anatomical injury scoring is characterized as a static summary of injuries based on clinical, radiological, and

Table 1 Some Existing Trauma Scores, Scales, and Triage Acronyms

Year[a]	Abbreviations	Names	References
1970	AIS	Abbreviated injury scale	14
1971	TI	Trauma index	13
1974	GCS	Glasgow Coma Scale	2
1974	TISS	Therapeutic intervention scoring system	38
1974	ISS	Injury severity score	16
1980	TI	Triage index	10
1980	TRISS	Trauma-injury and severity score	18
1981	TS	Trauma score	10
1981	APACHE	Acute physiological and chronic health evaluation	34
1982	PGCS	Pediatric GCS	29
1987	PTS	Pediatric trauma score	28
1987	OIS	Organ injury scale (AAST)	14
1988	PRISM	Pediatric risk of mortality score	30
1989	AP	Anatomical profile	26
1989	RTS	Revised trauma score	11
1989	T-RTS	Triage version of RTS	11
1990	ASCOT	A severity characterization of trauma	43
1994	UST	Uniform scoring system for trauma (Utstein style)	48
1994	APSC	Acute physiology score for children	31
1996	ICD-9-CM	ICD-9 clinical modification based on AIS and ISS	43
1996	TOXALS™	Toxic Advanced Life Support™	93
1997	NISS	New ISS	25
2001	ASPTS	Age-specific pediatric trauma score	34
2002	PAAT	Pediatric age-adjusted TRISS	40
2003	START	Simple triage and rapid treatment	91
2003	JUMP-START	Pediatric version of START	92

[a]Year listed is the initial year the scoring system was published; most have been updated from time to time.
Abbreviations: AAST, American Association for the Surgery of Trauma; ICD-9, International Classification of Disease, ninth revision.

surgical or postmortem descriptions of trauma involving various anatomical structures (e.g., cervical spine fracture, ruptured spleen, and aortic tear). Such systems are useful for classifying and quantifying the injury severity for epidemiological research and can be obtained retrospectively. **Anatomical scoring is less useful than physiological data for triage decisions; it is more predictive when used in combination with physiological parameters for quantifying outcomes.** The most frequently used anatomical scoring systems are the abbreviated injury scale (AIS), injury severity score (ISS), new injury severity score (NISS), and the anatomical profile (AP) (Table 1) (1).

Physiological impairment scores describe the acute dynamic physiological reserve in response to injury. These are measured through vital signs and levels of consciousness. The Glasgow Coma Scale (GCS), trauma score (TS), and revised trauma score (RTS) are the most commonly employed scales of measurements (1,2).

Combined scoring systems are mainly used for "outcome predictions" in trauma patients. The quantified physiological and anatomical data of the individual patient are used to calculate survival probability. Based on these probabilities, trauma scores, age, comorbidity, and other selected parameters reflect the patient outcome. The purpose of these assessment tools is the accurate prediction of patient survival and functional recovery. The major application of these predictive scores is in the realm of quality improvement.

FREQUENTLY USED SCORING SYSTEMS

Glasgow Coma Scale

The GCS is among the most well-known and established scoring systems used in trauma and evaluates the patient by ranking their ability to open their eyes, move their extremities, and vocalize. The GCS was first introduced in 1974 by Teasdale and Jennett (2) as a clinical aid to assess patients with impaired consciousness or coma, and is utilized as a neurological performance scale for both trauma and nontrauma neurological conditions. **The GCS correlates with clinical outcome when used in isolation, as well as when combined with other physiological scoring systems (3,4).**

The GCS assesses eye-opening, verbal response, and best motor response on a scale ranging from 3 to 15 (Table 2). An entirely response-less patient will achieve a GCS of 3, and a GCS of 15 reflects a completely normal response. The GCS is nonparametric (e.g., 12 being twice as good as 6) and does not incorporate brainstem reflexes (5). However, the scores of all three elements should rise and fall together. When there is a large discrepancy in one of the three elements compared to the other two [e.g., the motor score is one but the eye and voice score combined add up to nine (the maximum achievable)], then the patient is not comatose. Rather, the patient is likely to be affected by another neurological process (e.g., spinal cord injury).

Scores of 13 to 15 are classified as "mild" head injury. This initial value does not exclude some degree of

Table 2 Glasgow Coma Scale

Behavior	Best response	Score
Eye opening	Spontaneous	E4
	To verbal command	E3
	To pain	E2
	None	E1
Motor response	Follows commands	M6
	Localizes	M5
	Withdraws	M4
	Abnormal flexion	M3
	Abnormal extension	M2
	None	M1
Verbal response	Oriented × 2 +	V5
	Confused conversation	V4
	Inappropriate words	V3
	Incomprehensible sounds	V2
	None	V1

Source: From Ref. 2.

parenchymal lesions or the need for further clinical evaluation, especially in elderly patients or those with coagulopathy or small lesions near vital regions of the brain that may develop (6). GCS 9 to 12 is "moderate" head injury, and a scale ≤ 8 is considered "severe" head injury (Volume 1, Chapter 23, and Volume 2, Chapter 12). The GCS is simple, predictive, and easy to use. Some studies have shown a significant inter-rater variability, adversely affecting both clinical evaluation and reliability (7,8). However, variability in GCS invariably results from improper training of the examiner. When properly trained, the GCS interobserver variability is essentially eliminated.

A modification of the GCS is often employed to describe the intubated, sedated, and paralyzed patient. Many investigators would score these patients as "3-T" ("T" designating "tube"), thereby assigning a subjective clinical assessment of the patient's "verbal" ability, based upon the eye and motor scores—a practice that can affect treatment (9). This convention is acceptable, provided that the patient has a combined nonverbal score of seven or less. However, if the patient has a GCS of eight or more in the eye-opening and motor components, the clinician should determine if the patient is able to point at words or write out answers using a clipboard or eraser board. Patients designated as 10-T typically demonstrate orientation and verbal abilities equivalent to a GCS = 15. Accordingly, these patients should not be reported as 10-T or 11-T, but rather as awake, alert, and following commands. Indeed, these patients can often write out the answers to questions relating to person, place, and time.

Pediatric evaluations are difficult on account of the unwillingness of young children to cooperate with strangers, and age-related developmental limitations of their verbal and motor response. A pediatric adaptation of the GCS is shown in this chapter and is further discussed in Volume 2, Chapter 15.

Trauma Score and Revised Trauma Score

Champion et al. (10) developed the TS in 1981 as a modification of the trauma index, first described in 1980. They found that a combination of five physiological parameters (eye-opening, verbal response, motor response, capillary refill, and respiratory response) showed a good correlation with mortality resulting from blunt trauma. Systolic blood pressure (SBP) and respiratory rate (RR) were added and

Table 3 Revised Trauma Score

GCS	SBP	RR	RTS coded value
13–15	>89	10–29	4
9–12	76–89	>29	3
6–8	50–75	6–9	2
4–5	1–49	1–5	1
3	0	0	0

Note: Aggregate score <11 or any coded value <4 indicates need to triage to a trauma center.
Abbreviations: GCS, Glasgow Coma Scale; RR, respiratory rate; RTS, revised trauma score; SBP, systolic blood pressure.
Source: From Ref. 11.

the TS was created as a reliable tool for both field triage and patient outcome determinations. It indicates the severity of injury through physiological response as a numerical assessment of cerebral and cardiopulmonary system function. TS is limited because of the difficulty in assessing capillary refill and respiratory response under prehospital conditions.

In 1989, Champion (11) developed the RTS to eliminate the shortcomings of the TS. The RTS uses three of the physiological parameters from the TS (GCS, SBP, and RR) for triage and outcome. Ranges are specified and assigned a coded value (Table 3). The triage version, T-RTS, is the sum of the three coded values between 0 and 12. A T-RTS < 11 (or any coded value <4) indicates the need for triage to a trauma center.

The RTS is a good outcome predictor when the coded values are multiplied by weighted coefficients (derived from the Major Trauma Outcome Study), according to the following equation:

$$\text{RTS} = 0.9368\ \text{GCSc} + 0.7326\ \text{SBPc} + 0.2908\ \text{RRc}$$

The coefficient values assigned reflect the ability of each parameter to affect the outcome, with the highest assigned weight given to the GCS, which indicates that head injuries impact the outcome more than the initial SBP or RR. The RTS values range from 0 to 7.8408, with a higher value indicating increased probability of survival (Ps) (Table 4).

The RTS is limited by exclusion of age and other comorbidities; both factors affect the outcome and could potentially affect triage (12). The TS and the RTS are simple to use,

Table 4 Patient Survival Probability According to the Integer Values of the Revised Trauma Score

RTS	Ps
7.84	0.988
7	0.969
6	0.919
5	0.807
4	0.605
3	0.361
2	0.172
1	0.071
0	0.027

Abbreviations: Ps, probability of survival; RTS, revised trauma score.
Source: From Ref. 11.

accurate, and have been incorporated into the trauma score-injury severity score (TRISS) methodology (described in detail later in this chapter). These scores are widely used as the predominant physiological scoring parameters.

In 1971, Kirkpatrick (13) devised a scoring system called the "trauma index" (TI) that incorporated physiological and anatomical data. Although the TI was found to be predictive, it has not been as widely used as the others (13).

Organ Injury Scale

The Organ Injury Scale (OIS) was developed by the American Association for the Surgery of Trauma (AAST) in 1987 (14). Don Trunkey was the President of the AAST that year and the principal individual in charge of devising the OIS to facilitate clinical research. The resultant classification scheme is fundamentally an anatomical description, scaled from one to six, with one representing the least severe injury, five the most severe that is salvageable, and six, non-salvageable (in the case of a liver injury, also essentially lethal) (14). The first version covered liver, spleen, and kidney injuries. Since 1987, several revisions have occurred and other organs added. Currently, there are OIS characterizations for lung, heart, chest wall, diaphragm, abdomen, blood vessels, ureter, bladder, and urethra, in addition to the original three organs. These OIS schemes continue to be updated periodically for each organ.

Abbreviated Injury Scale

The AIS is an anatomically based global scoring system that classifies each injury in various body regions according to its relative importance on a six-point ordinal scale (15). It is not defined by physiological change, except for limited clarification purposes. The AIS was initially developed in 1969 as a uniform tool to quantify blunt injuries sustained in motor vehicle accidents by a consortium of the American Association of Automotive Medicine, American Medical Association, and the Society of Automotive Engineers (15).

The AIS has since expanded considerably and is revised and updated every 5 to 10 years. There are over 2000 injury descriptions in the latest 1998 version (AIS-95), which includes clarifications and the OIS (described earlier) that was developed to facilitate wider application in clinical research. An updated AIS-2005 is expected to be released in late 2006. The AIS scores have been mapped to the International Classification of Disease (ICD) codes. The most widely used ICD version is the 9th edition. When the ICD-9 codes are clinically modified by adding the AIS, they are referred to as ICD-9-CM injury codes. ICD-10 is currently being modified for AIS designations and is currently available in some jurisdictions.

Each injury is assigned a score from one to six (Table 5). The AIS score is based on the injury's anatomical site, type of injury and severity, and represents the "threat to life" association with the injury. It does not indicate outcome or include other parameters, and is exclusively descriptive.

The purposes of AIS are to (*i*) describe the injuries anatomically, (*ii*) standardize injury terminology, (*iii*) rank injury by severity, (*iv*) facilitate injury comparisons, (*v*) consider injury, not consequence, and (*vi*) stay time-independent.

The AIS is the most frequently modified and used anatomical scoring system, continuously expanding to accommodate changing clinical demands. Its limitations are mainly in describing physiologically based injuries and specifying them. It cannot accurately describe all fractures and locations (e.g., anterior, posterior, bilateral), contusions commonly seen together in the same region (e.g., rib fractures and pulmonary contusions), near-drowning, hypo- and hyperthermia, or inhalation injuries. Scoring systems based on AIS must also be assessed for these shortcomings.

Table 5 Abbreviated Injury Scale

AIS score	Injury
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Unsurvivable

Abbreviation: AIS, abbreviated injury scale.
Source: From Ref. 15.

Injury Severity Score

The ISS is an anatomical scoring system introduced by Baker et al. (16) in 1974. It was developed as an extension of AIS, as an ordinal summary severity score of a patient with multiple injuries. ISS correlates with mortality, morbidity, hospital stay, and other measures of severity. It is the most widely accepted severity-of-injury index in use today. However, NISS and AP described later in the chapter both outperform the ISS in predicting survival (17).

Each injury is assigned an AIS code and classified in one of six body regions, as follows: (*i*) head/neck, (*ii*) face, (iii) thorax, (*iv*) abdomen, (*v*) extremities (including pelvis), and (*vi*) external (15). The highest scores from the three most severely injured regions are squared and then added together to provide the ISS score (i.e., $ISS = a^2 + b^2 + c^2$) (16). Any injury assigned the AIS score 6 is automatically given the maximal score 75. ISS values are from 0 (no injuries) to 75 (incompatible with life), with the higher scores indicating increased severity. An example of ISS calculation and expected outcomes based on the ISS encountered is shown in Table 6.

Table 6 An Example Injury Severity Score: Calculation for a Patient with Multiple Injuries as Shown

Body region	Injury description	AIS	Square top three
Head and neck	Cerebral contusion (severe)	4	16
Face	Minor injury	1	<not factored in>
Chest	Flail chest	5	25
	Pulmonary contusion	5	
Abdomen	Minor liver contusion	2	25
	Complex spleen rupture	5	
Extremity	Fractured femur	3	<not factored in>
External	No injury	0	<not factored in>
		ISS:	66

Note: To calculate the injury severity score (ISS), only the highest abbreviated injury scale (AIS) score in each body region is used. The three most severely injured body regions have their score squared and added together to produce the ISS score. In this example, two major injuries occurred in the chest (both with an AIS = 5), but only one of the injuries was used (i.e., highest AIS from each of the top three body regions. The AIS values are derived from Table 5.
Abbreviations: AIS, abbreviated injury scale; ISS, injury severity score.

Table 7 Injury Severity Score and Relationship with Mortality

ISS	Prognosis/outcome
10	Unlikely to cause death
15	Major trauma, but mortality is less than 10%
17	Critical value
>25	Linear increase of mortality
50	50% probability of mortality
75	Nonsurvivable injury

Note: Calculation of ISS $= A^2 + B^2 + C^2$ using most severe AIS for three most severely injured body regions (see example provided in Table 6).
Abbreviations: AIS, abbreviated injury scale; ISS, injury severity score.

ISS limitations are its one-dimensional representation of the trauma patient's wide variety of multiple injuries. Equal (correctly evaluated) AIS scores in different body regions can give identical ISS scores, but represent a wide variety of injuries with vastly different outcomes. Furthermore, multiple injuries in the same body regions are not taken into consideration, because ISS uses only the highest, rather than the overall, score from the body region (e.g., in penetrating trauma or multiple abdominal bullet wounds) (18). Any error in AIS scoring decreases the subsequent ISS precision (19–21). Age and comorbidity are not taken into account, and severe neurological trauma is underestimated (22).

ISS is nevertheless the most widely accepted severity injury index for multiple trauma, and its value correlates with mortality. When the ISS is ≤ 15, there is less than 10% risk of mortality; an ISS $= 17$ is a critical value, and ISS > 25 increases linearly with mortality (Table 7). Although ISS has not incorporated multiple injuries in the same region, a modified version, the NISS, gives a more accurate prediction by calculating the three highest AIS scores regardless of body regions. This modified version is easier to use (17,23–25).

Anatomical Profile

In an effort to address ISS limitations, the AP was derived in 1989 as a more accurate descriptor of multiple anatomical injuries. The AP uses four components, A–D, representing all body regions, as seen in Table 8. The A–C components summarize all the serious (AIS 3–5) head, neck, thorax, and other body regions (26). Component D injuries are less serious (AIS < 3) and have not shown significance in mortality outcome predictions, but are useful for disability outcome assessments. The scores are combined using the square root of the sum of the squares of the AIS scores for all the injuries to give the AP component values as per the AP equation:

$$\sqrt{\sum (\mathrm{AIS})^2}$$

The AP assigns a decreased value for any individual injury as more injuries are calculated in aggregate. Patients with untreatable injuries (AIS 6) are not evaluated in the AP. APs improved assessment over ISS lies in its inclusion of all severe injuries; whereas ISS only includes the most severe injury from each body region. Patients with equal ISS scores but dissimilar AP scores give very different outcome predictions, whereas those with equal AP scores generally have similar outcomes, regardless of their ISS scores (27).

Pediatric Scoring

The pediatric trauma score (PTS) is useful and accurate for the physiological and anatomical differences unique to pediatric patients. Pediatric trauma patients present specific problems related to their differences from adults in terms of physiology and injury mechanism. They are especially susceptible to head trauma, and often have multiple injuries that are not immediately apparent.

The PTS (Table 9), first introduced in 1987 by Tepas et al. (28), is the most frequently used trauma scoring system in the pediatric trauma population. The PTS can identify critical pediatric patients more accurately than other scoring systems because it incorporates six parameters specific to injured children. During the initial assessment, each parameter is evaluated and given the numeric score +2, +1, or −1; accordingly, the aggregate score can range

Table 8 Anatomical Profile Components, Area of Injury, Abbreviated Injury Scale Severity, Injury Severity Score Body Region, and International Classification of Disease, Ninth Revision, Clinical Modification Codes

Component	Injury	AIS severity	ISS body region	ICD-9-CM codes
A	Head/brain	3–5	1	800, 801, 803, 850–854
	Spinal cord	3–5	1, 3, 4	806, 950, 952, 953
B	Thorax	3–5	3	807, 839.61/71, 860-862, 901
	Anterior neck	3–5	1	807.5/.6, 874, 900
C	Abdomen/pelvis	3–5	4	863–868, 902
	Spine without cord	3	1, 3, 4	805, 839
	Pelvic fracture	4–5	5	808, 839.42/.52/.69/.79
	Femoral artery	4–5	5	904.0/.1
	Crush above knee	4–5	5	928.00/.01, 928.8
	Amputation above knee	4–5	5	897.2/.3/.6/.7
	Popliteal artery	4	5	904.41
	Face	1–4	2	802, 830
D	All others	1–2	1–6	—

Note: The injury severity score body regions are: 1, head and neck; 2, face; 3, chest; 4, abdomen; 5, extremities (including pelvis); 6, external.
Abbreviations: AIS, abbreviated injury scale; ICD-9-CM, International Classification of Disease, ninth revision, clinical modification; ISS, injury severity score.
Source: From Ref. 43.

Table 9 Pediatric Trauma Score

Component	Category		
	+2	+1	−1
Child weight (kg)	More than 20	10–20	Less than 10
Airway	Normal	Maintainable	Nonmaintainable
Systolic blood pressure (mmHg)	Greater than 90	90–50	Less than 50
Central nervous system	Awake	Obtunded/LOC	Coma/decerebrate
Open wound	None	Minor	Major/penetrating
Skeletal fractures	None	Closed fracture	Open/multiple

Abbreviation: LOC, loss of consciousness.
Source: From Ref. 28.

from −6 to +12. A combined PTS ≤ 8 indicates recommendation for transfer to a trauma center. A combined PTS 9–12 represents minor trauma, PTS 6–8 is potentially life threatening, PTS 0–5 is life threatening, and a combined PTS < 0 is usually fatal.

The Pediatric Glasgow Coma Scale (PGCS) is identical to the GCS, except for the verbal response category, which is adjusted for children and infants who can be difficult to evaluate due to underdeveloped language and coping skills. Similar to the GCS, the PGCS values range between 3 and 15; and, just as with adults, it is especially valuable to break down the results (i.e., V, E, M) (29). The verbal scoring differences between the PGCS and the GCS are summarized in Table 10.

The pediatric risk of mortality (PRISM) (30) and the acute physiology score for children (APSC) (31) are the additional commonly employed scoring systems. Although these are used in some pediatric ICU settings, they are not developed specifically for trauma patients.

Many pediatric trauma centers use the adult scoring systems (RTS, ISS, TRISS, and NISS) for children in an effort to minimize input error (i.e., data abstractors only need to learn one system). Several studies have failed to demonstrate any benefit of having personnel learn the additional scoring systems (32,33). However, there remains some disagreement as to the benefits of certain comparative studies (e.g., RTS or ISS) in the pediatric population.

Another important pediatric weighted score is the age-specific pediatric trauma score (ASPTS), which uses age-specific thresholds for SBP, pulse, RR, and also utilizes the PGCS (34). The ASPTS score predicts mortality with a sensitivity that is similar to the RTS, but with greater specificity (34,35).

Acute Physiological and Chronic Health Evaluation

The acute physiological and chronic health evaluation (APACHE) scores the severity of illness as a predictor of outcome. The APACHE scoring system is the best-known and most frequently used predictor of patient outcome in the ICU. However, it is not designed specifically for trauma patients. APACHE was first introduced in 1981 by Knaus et al. (35). It was later refined to APACHE II in 1985, and an adjusted and weighted APACHE III was introduced in 1991.

APACHE II includes 12 physiological variables (including blood test results), age (starting at ≤ 44 years old), and a chronic health score. The values with the greatest deviation from normal within the first 24 hours are recorded. Each of the three categories is added up, coefficients are assigned to ICU-specified diseases and an APACHE score between 0 and 71 is calculated, with increased scores indicating the more severe illness. Weighted coefficients for emergency surgery and probable outcome are included.

Although APACHE II benefits from its now 20-year-old database, it is not very useful in trauma patients because it lacks specific data entry points for surgical or trauma conditions (36). Indeed, APACHE II lacks a component to accurately assess the full extent of acute trauma-related illness in previously healthy individuals, as opposed to patients with more chronic conditions. The sensitivity for trauma patients without a head injury has been shown to be particularly low (37). Keen (38) developed a therapeutic scoring system which is increased with more severe trauma, but similar to APACHE II this system does not have a specific trauma focus.

APACHE III is the newest iteration and has been shown to be more accurate for characterizing critically ill patients than APACHE II. Medical advances, expansion of diagnoses, and more complex injury conditions are taken into account. However, similar to APACHE I and II, this most recent version lacks any specificity regarding the trauma patient. Furthermore, the APACHE III has yet to be widely endorsed, as it involves 17 physiological values, and its coefficients and equations are not freely available (39).

Table 10 Comparison Between Verbal Response Criteria Used in the Glasgow Coma Scale and the Pediatric Glasgow Coma Scale

GCS—best verbal response criteria	Pediatric GCS—best verbal response criteria	Score
Oriented × 2 +	Smiles, orients to sounds, follows objects, interacts	V5
Confused conversation	Cries but consolable, inappropriate interactions	V4
Inappropriate words	Inconsistently consolable, moaning	V3
Incomprehensible sounds	Inconsolable, agitated	V2
No vocal response	No vocal response	V1

Abbreviation: GCS, Glasgow Coma Scale.

QUALITY ASSESSMENT SYSTEMS

Trauma Score–Injury Severity Score

The TRISS is used for outcome prediction, quality assessment, and improvement. The TRISS methodology was developed in 1980 as a logistical regression model to calculate survival probability in trauma patients by using combined initial admission ISS and RTS scores, along with the age of the patient.

The Ps is calculated as follows:

$$\mathrm{Ps} = 1/(1 + \mathrm{e}^{-b})$$

The coefficient b is calculated by the following equation:

$$b = b_0 + b_1(\mathrm{RTS}) + b_2(\mathrm{ISS}) + b_3(\mathrm{age})$$

e = 2.718282, the base of Napierian logarithms

The TRISS coefficients $b_0 - b_3$ are weighted values derived from the multiple trauma outcome study (MTOS) database (Table 11) with differing values obtained for blunt and penetrating trauma. The regression weights from the MTOS database are as follows: GCS = 0.9368, SBP = 0.7326, RR = 0.2908. For patients <15 years of age the coefficients for blunt trauma are always used. As regards the "age modifier," a 5-point scale is provided in Table 12. If age is ≤54, then the age modifier = "0," and if the age is >55, then the age modifier varies between one and four (≥85 years). An illustrative example is provided in Table 12.

Charts for trauma injury group predictions were developed from the TRISS methodology as visual references to evaluate survival probability and patient outcome. A preliminary outcome (PRE-chart) analysis can be set up as a graph for patients from one age group, with ISS (X coordinate) and RTS (Y coordinate). In this way patients may be plotted as L (survivor) or D (nonsurvivor), and a diagonally descending line Ps(50) representing the survival probability = 0.50, by setting $b = 0$ in the equation (3). Patients with unexpected outcomes can then be visualized and systematically reviewed, while remembering that each plot is a probability and allowing for statistically expected deviations. The statistical definitive patient outcome evaluation (DEF-chart) allows comparison of patient survival in a group (hospital) to a base-line norm using the z and W statistics (18).

The TRISS method predicts trauma patient outcomes on the basis of their injuries and enables comparisons of patient outcomes among trauma systems while controlling for differences in injury severity. The limitations of the TRISS method relate mainly to the anatomical component of the ISS, thus limiting injuries per body region; and, severe neurological trauma is imperfectly weighted, giving inaccurate predictive estimates in adult and pediatric trauma (40). Additionally, the age parameter has an incomplete grading range (41). Since MTOS-derived coefficients are used in TRISS, these will be somewhat limited by MTOS data collecting and its predictability is lower with nonMTOS coefficients (see below description of the MTOS) (42). Newer TRISS coefficients based on AIS-90 injury coding have been introduced. However, few studies have as yet been based on these newer values, which assign greater weight to penetrating trauma, and probably increase TRISS outcome predictions.

Table 11 Trauma Score Injury Severity Score: Values for Weighted Coefficients Derived from the Multiple Trauma Outcome Study Database

	Blunt	Penetrating
b_0 (constant)	−1.2470	−0.6029
b_1 (RTS)	0.9544	1.1430
b_2 (ISS)	−0.0768	−0.1516
b_3 (age)	−1.9052	−2.6676

Abbreviations: ISS, injury severity score; RTS, revised trauma score.
Source: From Ref. 18.

Table 12 Trauma Score Injury Severity Score: Probability of Patient Survival Example Calculation for a 45-Year-Old Blunt Trauma Patient

ISS = 42 (Table 6)

GCS: 10, SBP 85, RR 28.

RTS (coded value × weight) $= 3(0.9368) + 3(0.7326) + 4(0.8724) = 8.4978$

$b = -1.2470 + (0.9544)(8.4978) + (-0.0768)(42) + (-1.9052)(0) = 3.6377$

$\mathrm{Ps} = 1/(1 + 2.718282^{3.6377}) = 0.97436$

The patient's survival probability is 97%.

Note: Age is divided into a 5-point scale (0–4): age ≤54 = 0; age 55–64 = 1; age 65–74 = 2; age 75–84 = 3; age ≥85 = 4.
Abbreviations: AIS, abbreviated injury scale; GCS, Glasgow Coma Scale; ISS, injury severity score; Ps, probability of survival.

A Severity Characterization of Trauma

Champion et al. (43) developed a scoring tool, termed "A Severity Characterization of Trauma" (ASCOT) in 1990, in an effort to improve TRISS methodology. In the ASCOT scoring system, the anatomical component of the ISS was replaced with AP to improve outcome prediction by eliminating ISS shortcomings (44). ASCOT is a Ps calculation which uses AP components (Table 8), the RTS-coded values of GCS, RR and SBP, AIS, and patient age. ASCOT Ps is calculated as described in Table 13.

The ASCOT Ps utilizes the A, B, and C components of the AP. However, the AP component D was excluded; it is an important contributor to morbidity predictions but shows no significant contribution to mortality. The "*K*" variable in

Table 13 A Severity Characterization of Trauma Probability of Survival Calculation

Formula and parameters
$\mathrm{Ps} = 1/(1+\mathrm{e}^{-\mathrm{k}})$
e = 2.718282, the base of Napelarian logarithm
$\mathrm{k} = \mathrm{k_c} + \mathrm{k_1 G} + \mathrm{k_2 S} + \mathrm{k_3 R} + \mathrm{k_4 A} + \mathrm{k_5 B} + \mathrm{k_6 C} + \mathrm{k_7 age}$
k = weighted coefficients for blunt or penetrating trauma, see Table 14.
G = RTS-coded GCS
S = RTS-coded systolic blood pressure
R = RTS-coded respiratory rate
A, B, C = components of the AP (AIS 3-5)

Note: Age for a severity characterization of trauma probability of survival calculation is divided into a 5-point scale (0–4): age ≤54 = 0; age 55–64 = 1; age 65–74 = 2; age 75–84 = 3; age ≥85 = 4.
Abbreviations: AP, anatomical profile; RTS, revised trauma score; GCS, Glasgow Coma Scale; AIS, abbreviated injury scale.

Table 14 A Severity Characterization of Trauma Model Coefficients for Both Blunt and Penetrating Trauma for Each Variable (*K*)

Variable[a] (*K*)	Blunt trauma	Penetrating trauma
Constant	−1.1570	−1.1350
G	0.7705	1.0626
S	0.6583	0.3638
R	0.2810	0.3332
A	−0.3022	−0.3702
B	−0.1961	−0.2053
C	−0.2086	−0.3188
Age	−0.6355	−0.8365

[a]The *K* variable abbreviations are: G, Glasgow Coma Scale (Table 2); S, systolic blood pressure upon arrival; R, respiratory rate; A, B, and C are summary abbreviated injury scale (AIS) scores of serious injuries (AIS > 2) to various body regions or systems (as shown in Table 6). A component (A, B, or C) value equals the square root of the sum of the squares of the AIS scores (Table 5) for a patient's injuries in the component.
Source: From Ref. 43.

ASCOT scoring differs between blunt and penetrating trauma (Table 14). All patients with extremely poor or very good prognosis on arrival were excluded from the logistic function model; AIS = 6/RTS = 0 and minor injuries with AIS = 1–2.

ASCOT has been compared to TRISS in numerous studies (45–49). There have been differences of opinions on the more accurate outcome system; ASCOT seems to be the better predictor, but comparisons are flawed by the variable uses of databases and weighted coefficients. Continuously updated versions of AIS, databases, and recalibration of weighted coefficients give a variety of comparisons, which are often confusing.

Both methods have their limitations in accurate survival predictions (45). ASCOT has been in use for over a decade, but is relatively new compared to TRISS, which is often preferred for being easier to use and less "error prone" (22). Both ASCOT and TRISS are "error prone" in the pediatric population. Recently, Shall et al. (40) compared a pediatric age-adjusted TRISS (PAAT) with standard TRISS and ASCOT scoring for outcome determination. Using PAAT provided a more accurate prediction of outcomes, compared to TRISS and ASCOT, which both had a tendency to underestimate survival (40).

TRAUMA REGISTRIES

Trauma scores are useless without a "norm," a standard from which individual hospitals and patient groups can draw comparisons for quality assessments. Trauma registries are data repositories that have been developed to serve as the normative database. Numerous registries have been developed locally, nationwide, and internationally, resulting in enormous collections of data. These data have been used to improve trauma scoring, triage, outcome evaluation, quality assessments, and for allocating resources. Unfortunately, the registries also vary greatly in their quality of data and method of data collection. Much of the information generated has been costly, with questionable applicability or long-term usefulness.

Trauma registries are modified from earlier limitations through continuous updating of data and recalibrating of coefficients. Epidemiological differences and developing medical technology continue to challenge trauma registries. The American College of Surgeons (ACS) Committee on Trauma (COT) is collecting data from U.S. trauma centers with the National Trauma Database. England, Scotland, Germany, Austria, Greece, Norway, Australia, and other countries all have their own trauma registries with the purpose of creating trauma norms that more accurately reflect their regional characteristics. Registries in specific areas such as pediatric trauma and head injury are in use, and a modern combat trauma registry is under way.

Major Trauma Outcome Study

The MTOS is a retrospective descriptive national trauma database organized in 1982 by the ACS-COT (46). Its purpose was to develop a national norm for trauma care, enabling hospitals to compare and evaluate the quality of care and outcomes of their trauma patients with a reference point, and to support trauma evaluation and quality assurance. Demographics, physiological, and anatomical injury severity, etiology, and outcome data from approximately 160,000 trauma patients were submitted on a voluntary basis from trauma centers throughout North America between 1982 and 1989. The injuries were coded according to the International Classification of Diseases, 9th Revision Clinical Modification (ICD-9-CM), severity scored (AIS-85 and ISS coding), and outcome norms were set using TRISS methodology. Unexpected outcomes were reviewed, and patients missing any of the required (mainly RTS) variables for calculating survival probability were excluded (47).

The MTOS has numerous limitations. The data is not population-based, as it was culled on a voluntary basis from a variety of institutions. Eleven percent of the patients were excluded on account of incomplete data, lack of GCS scoring of intubated patients, and registration of RR. This creates a potentially significant bias if these patients were the most severely injured or had the poorest outcome. MTOS does not implement comorbidity; there are no pediatric-specific norms, as data were collected from adults (age ≥15 years); and, the data are limited to inhospital outcome.

Despite these shortcomings, MTOS is now over 20 years old and a very useful and impressive database. Qualitative studies have shown that MTOS has improved the hospital trauma systems throughout North America and has been applied in the United Kingdom (U.K. MTOS) (47). Trauma registries have been developed throughout the world, some as offshoots of MTOS (e.g., U.K. MTOS), others as unique trauma databases reflecting their specialized regional epidemiology.

The Utstein Style: Uniformity in Scoring

In 1994, an international working group organized by the International Trauma Care Society (ITACCS) initiated the application of the Utstein concept to create a uniform method of reporting trauma data (UST) (48). The intention of the group was to find the widest possible consensus between the major forces in the field, and ITACCS published the recommendations in 1999 (49). The UST suggests a common terminology and template for the prehospital and early in-hospital management.

The template is created as a generic "object-oriented" approach; the patient is regarded as an object, traveling through time and space (locations) after a trauma incident. The object (patient) is periodically linked to other objective "links" (personnel, evaluations, treatments), along the "care" pathway. This gives flexibility within the model to record, evaluate, and refine the links individually to improve the model.

The ISS is used and thereby also AIS, RTS, and GCS. These recordings allow for TRISS methodology and comparison to MTOS. The patient cofactors of age, gender, and comorbidity are included and graded. Patient outcome is also graded, incorporating mortality and morbidity.

Data collecting is divided into "core" (mandatory) and "optional," but the extensive core data collecting makes training for data collectors necessary to minimize inter-rater variability, and using ISS may affect accuracy. The UST takes into consideration and eliminates many weaknesses of previous scales and registries (e.g., factor grading, and incorporating the morbidity and disability factors). This uniform-reporting style looks promising, facilitating regional and international cooperation. It could eliminate a number of the biases and variables presently encountered in trauma systems and increase registry system effectiveness as well as quality of care (48).

UST's limitations lay in collecting the extensive amount of core data, and the limitations of incorporating ISS. Definitions and classifications need some refining to facilitate clinical applicability (50).

TRIAGE DEFINITIONS AND GENERAL CONCEPTS

Triage is derived from the French word *trier* which means "to sort." **Triage is a process for categorizing victims involved in a multi-casualty incident or disaster into different degrees of severity, and also assigning appropriate graded treatment and transport priorities.** Dominique Jean Larrey, Napoleon's famous surgeon is often credited for devising the first modern methodology for quickly evaluating, categorizing the wounded in battle, and prioritizing their evacuation, based on the severity of their injuries with no regard to rank. In war, as in natural disasters, the number of patients often exceeds the amount of available personnel and/or equipment resources (51,52). Accordingly, the optimum triage model can vary in different situations. The maximum patient survival results when the best use is made of available resources.

Triage is a dynamic process, with reclassification of status possible after the transport and definitive treatment of the victim has occurred. The initial triage categorization should be seen as a temporary classification of the victims' condition, which is easily changed and affected by both victim- and nonvictim-related factors (53–56). The aim of every triage officer should be to achieve "The greatest good for the greatest number." Peacetime triage is performed in both the prehospital and inhospital settings.

Prehospital triage is the most commonly employed system of sorting patients on the basis of injury status and is performed at the site of the incident. In North America, (i.e., United States and Canada) physicians are not typically involved in the prehospital scene. In these cases, paramedics, emergency medical technicians (EMTs), and police and fire rescuers perform the first onsite triage. In mass casualty situations, physicians may be sent to disaster scenes to coordinate.

The "scoop triage" system is typically performed by nonhealth professionals such as police officers or firemen, and its main aim is to remove the victims from the hazardous incident site while performing limited initial triage. It by no means replaces the normal triage procedures performed by health professionals, and should only be considered as a rudimentary triage. It is also known as "scoop and run," when adequate transportation is available for immediate evacuation of the victims.

In most European countries, physicians are present at the scene of the incident in both minimal casualty situations and in disaster scenarios [manning mobile intensive care units (MICU), or emergency medical system (EMS) helicopters] and apply the onsite triage (54,57–59). An onsite advanced medical post (AMP) should be deployed in the case of severe multi-casualty incidents and in disaster situations. The AMP can include a chief emergency physician (CEP), a chief paramedic, and a chief nurse acting as staff officers managing the ongoing crisis, and effectively deploying emergency physicians (EP) paramedics, nurses, auxiliary health providers, and volunteers (52).

The inhospital triage is applied at the receiving hospital and is performed by emergency department (ED) physicians or nurses. There are numerous protocols applicable in triage, with significant differences, due partly to the fundamental prehospital system of medical care ("scoop and run" or "field stabilization"), and partly related to the philosophy of the individual medical care system, its social structures and traditions, and partly related to the type of incident (60,61). Civilian and military triage procedures and aims must be differentiated (52,56).

The main goals of triage procedures are to (*i*) prevent avoidable deaths, (*ii*) ensure proper initial medical treatment within a minimal time frame, and (*iii*) avoid misusing assets on hopeless cases.

TRIAGE APPLICATIONS

Triage should be applied whenever the number of patients exceeds the capabilities of the available resources (medical personnel and equipment) at the local level. Triage systems are also applied during disasters where the entire situation is de facto well beyond the capabilities of the regionally available resources, and likely to extend over a longer period of time (52,62,63).

During mass casualty incidents, triage officers must quickly determine which victims need immediate medical treatment and which can wait; which victims require emergency surgery and which are not endangered. The prognosis for the initially surviving victims deteriorates proportionally with the degree of injury, as well as the time elapsed between initial injury and the institution of appropriate treatment.

Use of Disaster Medical Assistance Teams

In recognition of the fact that the available EMS personnel and hospitals are often overwhelmed by mass casualty situations, the U.S. Department of Health and Human Services, in partnership with the Defense Department, the Veterans Administration, and the Federal Emergency Management Agency (FEMA) created the National Disaster Medical System (NDMS). It recruited inpatient beds from hospitals across the country, and signed memorandum of understandings (MOUs) with various health care agencies, which sponsored "Disaster Medical Assistance Teams" (DMATs) to augment local medical capabilities during times of disaster.

DMAT teams have been administered under the auspices of FEMA since the creation of the Department of Homeland Security (DHS) in 2002. Volunteers are considered "intermittent federal employees" when a disaster declaration is made. This indemnifies the DMAT members against medico-legal claims, and provides temporary licensure authority in all U.S. states, territories, and jurisdictions for the deployment duration.

Typically comprised of 100 to 150 medical professionals (physicians, nurses, paramedics, pharmacists, etc.) and support staff, organized DMATs are trained and prepared to activate as a group of about 35 members within six to eight hours of a major disaster. When activated, the DMAT members provide all of the gear, medications, and supplies (including water, food, generators, tents for environmental protection, etc.) so that a disaster area will be self sufficient for up to 72 hours. DMATs are capable of numerous missions, including: setting up triage and treatment sites, regional evacuation, and reception points, as well as assisting in augmenting overrun hospitals, hospital evacuations, and the provision of shelter medical care.

There are currently 52 DMATs of varying levels of readiness, in the United States, and over 30,000 designated "NDMS beds" in the country's hospitals are available for providing hospital bed surge capacity in the event of a major catastrophe.

In an additional effort to support disaster situations, several North American cities have instituted volunteer citizen training of its nonprofessional constituents into an organization known as a Community Emergency Response Team (CERT). These amateur emergency workers are typically community members who receive an introductory level of training in mass casualty management principles and become deputized as official auxiliaries to local government EMS and support services in times of large-scale community disasters.

Originally developed by the Los Angeles City Fire Department in 1985 for help with earthquake preparedness, FEMA made this training available nationally in 1993. In 2003, FEMA provided over $19 million in grant funds to states and territories to expand the CERT program under the direction of DHS. Every area in the world has natural disasters (most commonly floods, famine, hurricane, earthquakes, and tsunami), along with man-made disasters (e.g., chemical spills, transportation accidents, and more recently terrorist attacks on innocent civilians). The mass casualties created in all of these circumstances can be beyond the capabilities of the local governments (e.g., December 2004 Indian Ocean Tsunami, the Indo-Pakistan earthquake of 2005, and the levee breaks from Hurricanes Katrina and Rita, 2005). CERT training is now being provided worldwide. Basic information can be found on the FEMA website (64).

Out-of-Hospital Triage Principles

The first responders on the site should perform the initial triage, and unless relieved by more experienced personnel, should also provide oversight of the entire situation (56). The first physician (e.g., European countries) or paramedic (e.g., North American countries) arriving at the scene should organize the overall rescue procedure (utilizing DMAT and CERT personnel when deployed), and establishing—if not already done—the operational areas (assembly, triage, treatment, and transport areas) and "exclusion zones" where needed. All triaged victims must be re-evaluated at frequent, preset time intervals (51,59,65,66).

The assembly, triage, and transport areas must be situated in safe locations, where the rescue personnel and victims will not be further endangered by the incident (directly or indirectly) or by the environment. For example, following the Indian Ocean Tsunami of December 26, 2004, triage areas were set up on dry land, which was elevated above the water and debris lines, whereas, in Hurricane Katrina, triage areas were located on freeway overpasses, allowing for both dry land and helicopter access, and at the New Orleans International Airport, where patient reception, triage, treatment, and medical evacuations were performed for both rescuees as well as patients being evacuated from over a dozen hospitals. The triage area should be located immediately adjacent to both the assembly area and the treatment site (Fig. 1). The transport area should be located adjacent to the treatment area (but not too far from triage), to facilitate evacuation of both triaged and provisionally treated victims needing immediate transport to higher level of care (51,65–69).

Each victim is issued a color-coded triage card, when available, which contains a limited amount of medical information regarding the status of the victim, as well as identification information (51,65–71). A universally acceptable protocol for triage does not yet exist, however, there is improving international consensus on triage terminology, color coding, and symbol markings (70,71). A number of triage systems are used in various locales (Table 15). However, when massive casualties occur following natural disasters, involving multiple countries or when relief agencies from multiple countries are working together, the need for a uniform triage system becomes evident.

During the initial triage, patients are assigned a "treatment priority." The highest priority for treatment is assigned to victims with unstable or jeopardized vital functions, who can be rapidly stabilized through direct medical interventions onsite (e.g., compromised airway, tension pneumothorax, hemorrhage control, and mild to moderate hypotension).

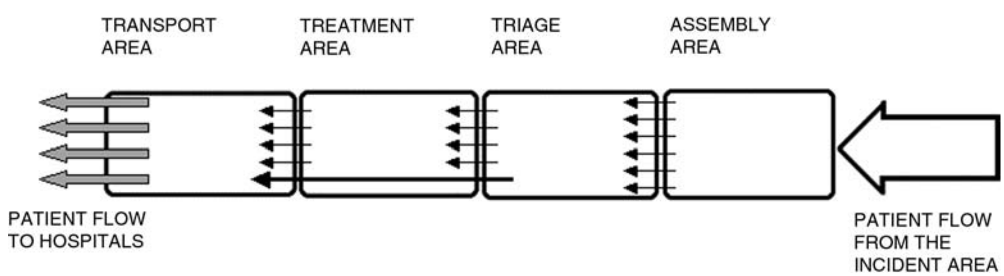

Figure 1 Optimum layout for managing patient triage and transport from the incident area to hospitals. The arrows show direction of patient flow. Some triage will occur at the incident area, but then patients are moved to an assembly area; obviously injured patients are carried through (or bypass) the assembly area into "triage" where they are assessed for immediate treatment and/or transport to a higher level of care. Following treatment, patients are transported to the appropriate level of care facility.

Table 15 Triage Methodologies Based Upon the Number of Triage Category Subsections

Subsection number	Triage category	Tag color	Description/comments
5	T1	*	Life-threatening situation needing immediate treatment
	T2	*	Emergency, but not life threatening
	T3	*	Nonemergency
	T4	*	Healthy, not injured
	T5	*	Dead
4	T1 Immediate	Red	Life-threatening situation needing immediate treatment (red tag)
	T2 Delayed	Yellow	Emergency, not life-threatening (yellow tag)
	T3 Minor	Green	Slightly injured, not moderately or severely injured, no survival chances (green tag)
	T4 (or T0) Expectant	Black	Dead or dying → morgue (black tag)
3	T1	*	Life-threatening situation needing immediate treatment
	T2	*	Emergency
	T3	*	Can wait
2	T1	*	Life-threatening situation needing immediate treatment
	T2	*	No immediate treatment needed
Scoop triage	T1	*	Possibly in life-threatening condition
	T2	*	No immediate treatment needed (presumed dead, clearly dead, or possibly in no life-threatening situation)

Note: The various categories and descriptions are provided for each triage method. The tag color descriptions are only provided for the four-subsection method (the most common).

*Variable: there is a variety of color schemes utilized for triage systems around the world. Only the four-subsection methodology has become internationally standardized as shown in table. See text for details.

Transport priorities (Volume 1, Chapter 7) are similar; a victim with unstable vital signs is given a high transport priority, when urgent medical interventions (such as emergency surgery, severe hypotension, uncontrollable hemorrhage, blood vessel injury) are not available on site are needed.

The triage priority is identified by a color-coded triage tag, although the color code and triage subsections (categories) are not universal.

The four subsections triage method, performed by health professionals (typically paramedics in North America, and physicians in Europe), is the most widely known and applied method (Table 15, and Figs. 2 and 3) (52,59,67,68) and utilizes the following basic structure:

Red (*first priority, T1*): Has the highest priority. The victim is in a life-threatening situation and requires immediate medical treatment at the scene and/or in the receiving medical facility to preserve the victim's life. These victims (must by definition), have a good prognosis for a satisfactory quality of life after the definitive treatment (51,59,65,66).

Yellow (*second priority, T2*): Seriously injured or a serious medical status, but with vital functions and, presently, stable. Requires medical treatment, but has a very good outcome (51,59,65,66).

Green (*third priority, T3*): All walking victims, with or without injuries. The injuries encountered here are minor (by no means life-threatening), and with an excellent prognosis.

In mass casualties, victims with the most severe injuries, and no real chance of survival despite the medical effort (e.g., full thickness burns >90% of total body surface, severe and open skull/brain injuries with a GCS = 3, etc.), are triaged to an "expectant" (green) area, implying survival predicted to be less than 24 hours. These victims are given palliative comfort treatment and have a low treatment, transport priority, and are defined as having no surviving chances. However, as additional resources are brought to the scene, patients in this category can still be retriaged back to either the red or yellow areas if indicated. In the military, the expectant area is often denoted by a dark blue color.

Black (*last priority, T4 or T0*): Dead. Death must be certified by a physician, unless the type of injury is obviously not compatible with life (e.g., decapitation, rigor mortis, total desiccation). In these cases, nurses and paramedics may certify the death (51,59,65,66).

In some European countries, the T4 color code is not black; rather, it is sometimes designated by white or blue. **A yellow-coded victim can rapidly deteriorate to red-coded status, just as a red-coded victim can improve to a green-coded status. The fluidity of triage status continues until definitive treatment of the victim occurs at the hospital.**

The data entry fields on the triage card should be intuitively organized (Figs. 2 and 3), so that a minimum amount of writing is required, and one can easily view the patient status. The information given by the card to the receiving physician in the hospital must clearly indicate known injuries and diagnosis, and should indicate any recommended treatment. The scoring system(s) applied must be pre-agreed by the members of all jurisdictions who will encounter the patient, typically county-wide, and ideally, nationwide (59,72).

In most countries, the data transferred to the triage card includes: patient's name and identification serial number (e.g., passport, driver's license, or social security number), demographic data (age or date of birth, sex), physiological data (given later in this chapter), known injuries, initial treatment (including medications administered) (Figs. 2A and 3A), overall status prior to transport, transport priority, means of transport (ambulance vs. air evacuation),

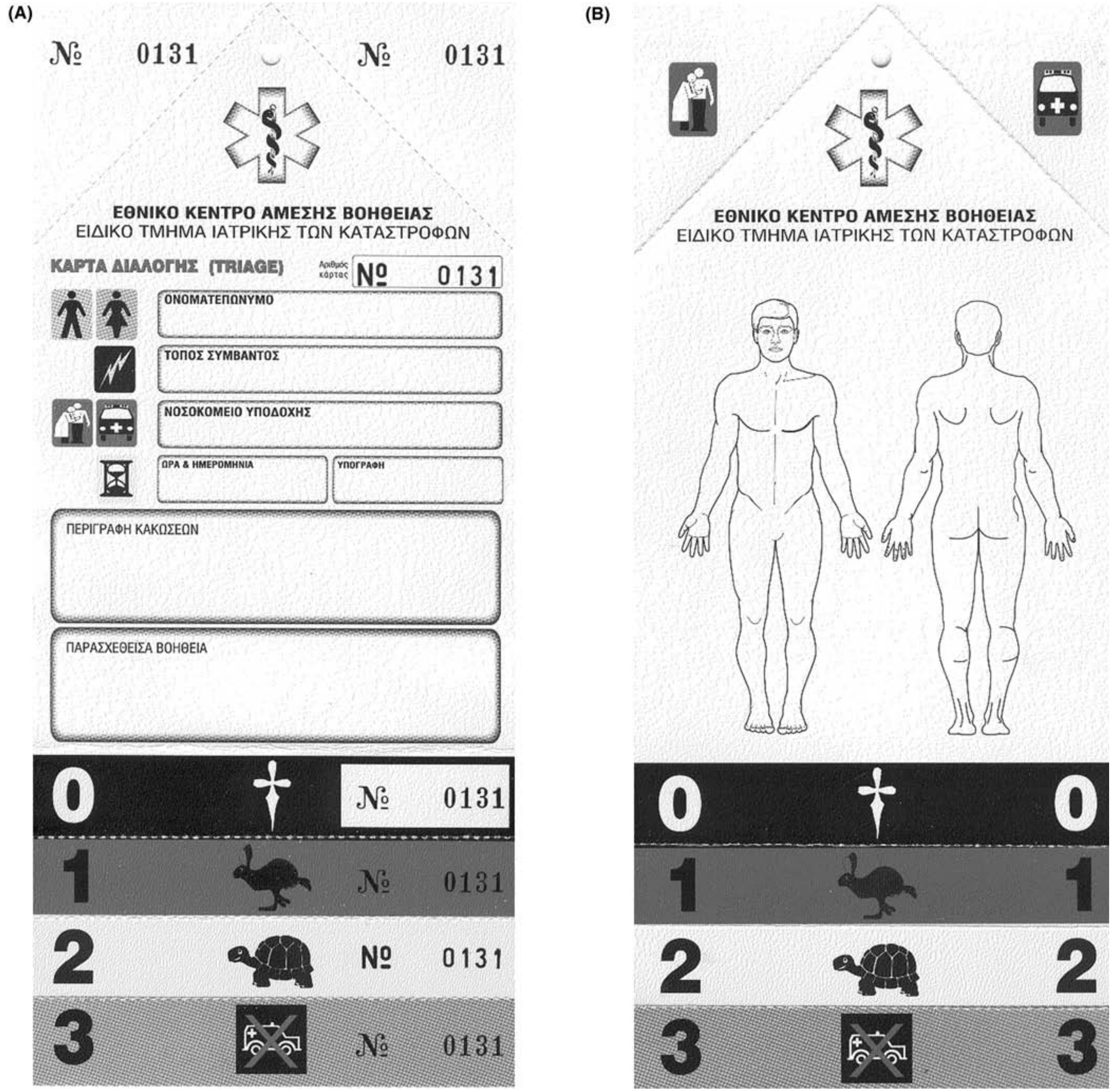

Figure 2 (**A**) Triage card, Greece (front side), showing color-coded tag typical of the four-subsection categorization of triage. In this case T0 (black) denotes death (no immediate need for treatment or transport); T1 (red rabbit) denotes highest level or urgency to treatment and transport; T2 (yellow turtle) denotes need for transport, but at less urgent pace; T3 (green) denotes no need for urgent transport. These cards also have designated areas for patient identification, as well as demographic and physiological data. (**B**) Triage card, Greece (back side), showing the color-coded four-subsection categorization of triage described in (A) and in Table 15. Also shown on this card are anterior and posterior patient body outlines where marks and notations can be made to delineate areas of trauma on the patient.

and destination (level I trauma center vs. lower level). The physiological data often include the GCS, blood pressure, RR, heart rate, O_2 saturation, and general status of the airway, breathing, and circulation.

The worldwide diversity of triage tags (Figs. 2 and 3) represents a problem that could potentially adversely affect patient care. Accordingly, the NATO members have all embraced the aforementioned color-coding nomenclature. The different cultures, healthcare-systems, prehospital care providers, and financial factors have thus far impeded the implementation of a unified triage tag for non-NATO nations (70,71).

In addition to the triage-tags-documentation, an independent on-scene "master triage report" should be compiled to include data regarding all affected and nonaffected individuals involved in the incident. This documentation should include recognition data for the individual, such as sex, approximate age, name if available, initial triage

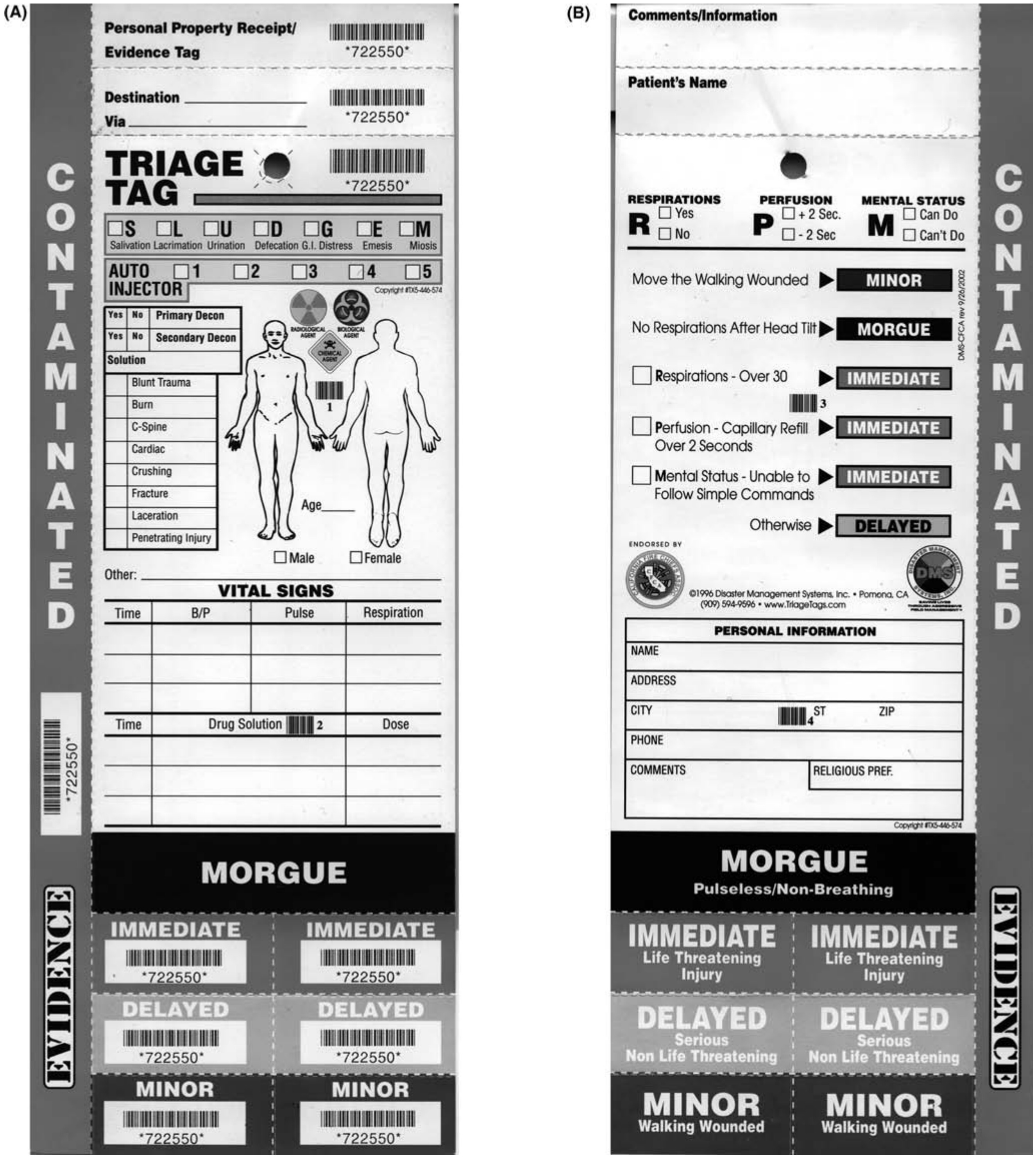

Figure 3 (**A**) United States Civil Disaster Management triage tag as used for START™-triage (front side). Information regarding chemical, biological, and radiological contamination is clearly indicated. Note bar-coding (top-right) allowing for quick digital identification of patient. The triage tag also has check-off boxes for symptoms (S, L, U, D, G, E, M). Additionally, auto injector use is indicated as well as decontamination status (primary versus secondary). Mechanisms of injury and vital signs are also noted. The bottom of the tag includes the four color-coded triage designations. Each may be torn off, increasing the triage level of urgency (with bar coding). (**B**) United States Civil Disaster Management triage tag used for START-triage (back side). Top of card indicates physical status of patient including respirations, perfusion, and mental status. Triage status and personal identification is noted here. The bottom of the tag includes tear-off triage level of urgency (corresponding with front side). The START-triage algorithm is provided in Figure 6.

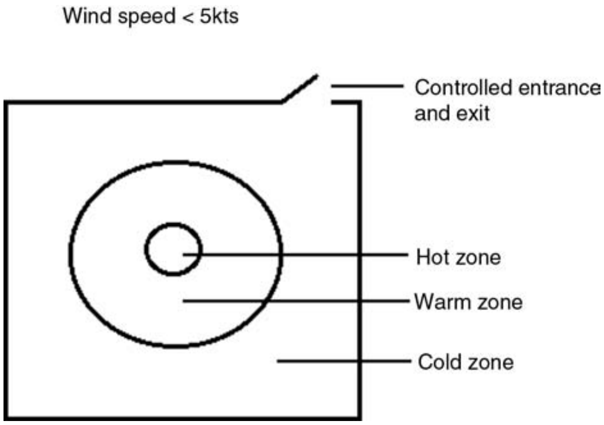

Figure 4 Exclusion zone for wind conditions less than five knots. In no wind and low (<5 knots) wind conditions, the exclusion zone can surround the hot zone, with a perimeter uniformly distanced from the center "hot" contamination site. A warm zone perimeter should allow entrance to rescuers wearing personal protective equipment only.

categorization and locality inside the incident area, where the victim was found, and eventually, the use of specialized rescue methods (extrication, etc.), as well as disposition.

In case of any hazardous materials (HAZMAT) release, the security of the rescue forces, and of the nonaffected population requires the establishment of "exclusion zones" (Figs. 4 and 5). **Decontaminated zones must be uphill, upwind, and upstream from the previous contaminated zone (2,59,72–74).** The designated site to establish the assembly, triage, treatment and transport areas must be chosen very carefully. The wind plays a vital role in safety, because not only wind direction, but also its speed determines the safe site. The exclusion zones are designated as "hot," "warm," and "cold" zones (51,59,72–80).

A "hot zone" is an absolute exclusion zone. The contamination (pollution) is far beyond the limits of safety,

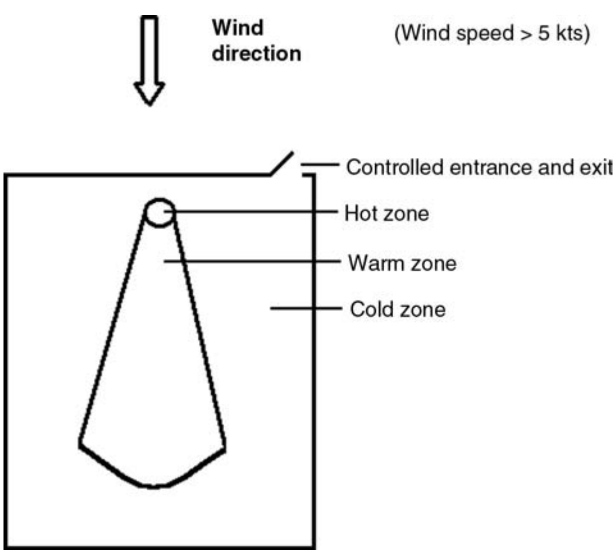

Figure 5 The exclusion zone for high wind conditions (>5 knots) is asymmetric in shape with extension down wind beyond the warm zone (area where contaminated materials may blow).

and represents an acute and real threat for rescue forces and victims. Entry into the hot zone is permitted only to authorized personnel, equipped with the appropriate personal protective equipment (PPE). PPE is divided into three levels (A, B, and C) depending upon the hazard present (see Volume 1, Chapter 39).

A "warm zone" is a contaminated zone and exclusion zone. Entry is permitted for authorized personnel only. The level of contamination (pollution) is high and threatening, but lesser than that occurring in the hot zone. Rescue forces must wear PPE, but of a lower level than those used the hot zone.

In a "cold zone" the contamination level is lower, but higher than that required by safety limits. No acute threat is present and no PPE is needed. It is essential to establish an exclusion zone inside the cold zone, outside of the warm zone, to set up the assembly, triage, treatment, and transport areas.

The size and location of these zones must be re-evaluated continuously on account of the changes in numerous externally influencing considerations. These factors include: The number of victims (unexpected rise of the number of casualties), environmental influences (wind speed or direction, rain, etc.), secondary incidents (after shocks, dam or levee breaks or tsunamis following earthquakes, delayed or persistent—HAZMAT release), crowd control, and space ergonomics (51,59,73–77).

Although the cold zone represents absence of direct hazard to the population not affected by the incident, it may need to become an absolute exclusion zone: rescue services should have an undisturbed focus on their job without distraction from "disaster-tourism."

In other situations, the type of incident in progress necessitates establishment of an absolute exclusion zone of a greater range to prevent a possible unrecognized spread of the contamination. Triage must be performed outside of the hot and warm zones unless it is not time-consuming (i.e., "instant-triage") and the rescue forces are not endangered. In this situation, PPE should be sufficient in quantity and quality to allow rescue forces to carry out objective triaging.

Sometimes a rapid triage can be performed in the warm zone through selection of victims who seem to be severely affected by the incident. These "rapidly triaged" victims must go through normal secondary triage procedures in the cold zone (73–81).

Treatment is performed solely in the cold zone. An exception can be a case of reasonable resuscitation efforts in the warm zone, providing the rescuers are not endangered. Space ergonomics inside and outside the zones are of vital importance. The incoming and outgoing roads for the ambulances must be established, as well as their parking spaces and proximity to the transport area.

A helipad must be emplaced, taking into consideration the helicopters' limitations with the flight path, approach-, landing-, and takeoff procedures (e.g., height above ground level, wind direction, presence of HAZMAT) (66,73–76).

These conditions are best created in collaboration with the military or municipal police department. Crowd control is an additional police, military, or security task, which will be necessary at the incident, without which triage procedures are more difficult (52).

In-Hospital (Secondary) Triage

The principal purpose of in-hospital triage is prioritization of urgent life-saving treatment, (e.g., a splenic rupture is given a higher priority than an open lower extremity fracture with intact distal pulses) (82–86).

The in-hospital triage must also be disciplined and designed efficiently. Optimally, the triage area is physically directly before the entry into the ED, leaving the ED itself solely for treatment (54,66). In this model, obviously, life-threatening injuries will still pass through the triage area to be registered into the system, and enter the resuscitation bay of the ED.

Documentation procedures must be established to maintain oversight. All patients arriving from the incident area to the in-hospital triage area must be documented. This procedure is in addition to the on-site documentation, and the two must be compared after the incident.

The physicians and nurses performing triage at the receiving hospital must be experienced. In disaster situations, ED-response teams should be established before the arrival of casualties at the hospital (85,86). The victim's condition must be checked rapidly, incorporating all influencing factors, and subsequently the patient should be expeditiously triaged to one of three areas: (*i*) directly to the operating room area, for tertiary triage for emergency surgery, (*ii*) to a resuscitation area where complete primary (Volume 1, Chapter 8) and secondary survey (Volume 1, Chapter 14) will occur, or (*iii*) to an observation holding area or ICU where basic supportive care will occur (51,54).

It is not unusual to change the victim's triage categorization after the in-hospital triage, as a more detailed and accurate assessment occurs (62,87). In mass casualty situations, the in-hospital triage area often transforms a normal waiting room (or other nonclinical areas) into an extended ED (61).

LIMITATIONS AND PITFALLS OF TRIAGE

The first consideration when initiating triage is ensuring the safety of the rescue personnel (59,72). Rescue in a difficult environment may occasionally take priority over triage, which should then be performed as needed (88). In cases of entrapment, detailed triage occurs only after extrication. The extrication priority also employs a type of triage, giving highest priority to entrapped victims who are seriously injured, or in an unstable physical condition, or both (89,90).

The range of transportation resources available is an additional limitation to triage decisions. The availability of helicopters (or other means of rapid transport) to evacuate patients from a remote area can rapidly change a patient's possibility of survival (see Volume 1, Chapter 7). Conversely, the absence of air evacuation capabilities can convert an otherwise survivable injury into a lethal one (91).

The quantity of transport vehicles can also impact triage decisions. An insufficient number of vehicles may force the triage officer to downgrade the formal triage category to a lower priority, increasing the waiting time for the initially low priority cases, and subsequently resulting in the possibility of their upgrade to a higher priority as their respective condition changes. Conversely, over-commitment of transportation vehicles can also have adverse effects if unwarranted traffic and congestion makes the evacuation operation less manageable (52,59,71).

The predetermination of adequate medical supplies and logistics support in mass casualty incidents and disasters require an accurate forecast of incoming injuries and associated influencing factors. However, in large scale disasters, where chaos may be present, such information is often unreliable or not available. Inadequate local logistical support, on account of the financial shortages or inadequate training can doom an otherwise well-organized and promptly responding central relief effort (52,88). In this situation, the central authority may need to augment the local manpower with military trained rescuers.

The best triage officer is not necessarily the medical officer with the highest rank or seniority; rather, it is the physician with the greatest experience in triage. The triage officer must remain calm under stressful conditions, while deploying and applying the knowledge and experience required to benefit the largest possible number of victims (51,52). The rescue success is directly proportional to their medical capabilities, and inversely proportional to their physical and mental fatigue (53,62–66).

The ethical considerations in the triage procedures are dependent on religion, culture, local traditions, and institutional legacies. Deciding which patients are salvageable, and which are not, is imprecise and agonizing (51–53).

There is no universally applicable legal code for triage. Nations, states, and counties may have their own legal framework for triage situations. The triage officer should consider the legality of trans-jurisdictional transport needs, and act accordingly. Legal agreements should be prearranged, if possible, in cooperation with local and central authorities (52,72).

Communication is essential for any operation. The quality and quantity of the local telecommunication must be wisely distributed among the rescue forces. The personnel's training level in telecommunication determines the quality and flow of information exchanged, and can quickly become an informational jam, making correct triage procedure impossible to accomplish (52). Lack of uniformity in communications hardware and frequency use when mutual aid resources are brought to a distant disaster scene may add to the confusion.

Another frequent pitfall in triage situations is failure to consider the mental and physical fatigue of the rescue personnel and plan for relief. In mass casualty incidents and disasters, the rescuers often exceed their own physical, emotional, and mental limitations, thereby possibly disregarding hazards, making errors, and introducing other inaccuracies in triage procedures and decisions. All personnel involved in an extended rescue operation should be ordered to rest intermittently. The optimum endurance for a shift in mass casualty incidents and disasters varies between four and six hours, but the first crucial 12 hours of a response, when most of the victims who are entrapped are being located, often lead to poor shift compliance. Every shift should be ideally followed by an equally long rest period. Feeding and fluid administration is similarly important to maintain functionality of responders.

All rescue personnel should take part in debriefing or stress relief sessions held at the end of every day of operation, immediately after the end of the whole operation, and then again, approximately one month later. Specially trained psychologists or peer-trained Critical Incident Stress Debriefers should be responsible for these sessions (53,61). Trauma survivors should be told that symptoms of acute stress disorder (ASD) and post-traumatic stress disorder (PTSD) are common, natural, and treatable. However, if any of these symptoms [recurrent, intrusive recollections of the event (e.g., nightmares or flashbacks), avoidant behavior (e.g., emotional numbing), increased arousal (e.g., irritability, insomnia), or significant impairment in social and occupational functioning] should occur, trauma survivors should seek the assistance of a mental health professional so that the symptoms do not become permanent (see Volume 2, Chapter 65).

The financial aspects of this system are not to be ignored: A system based on the EPs is more expensive to establish and operate than the one using volunteers and EMTs. Thus, those systems that are affordable in the few wealthy regions of the globe are financially impractical in many other areas (66).

SPECIAL TRIAGE SITUATIONS

Civilian Mass Casualty: START/JumpSTART™

Many mass casualty situations (bomb blast, hurricanes, earthquakes, and tsunamis) result in patients suffering from both blunt and penetrating trauma, as well as environmental problems (near-drowning, dehydration, hypo- or hyperthermia). Often, devastating burns (Volume 1, Chapter 34) or near-drowning situations (Volume 1, Chapter 35) are also associated. The nature and mechanism of the injury, age of the patient, and special circumstances (described hereafter), suspicion of "hidden" injuries on account of its location in closed cavities (skull-brain trauma, thoracic trauma, abdominal trauma) must all be considered (54). A correct final triage "prediction" is based upon the recognition of trauma, the initial treatment applied, and the extent of delay until definitive treatment (54).

The jeopardized trauma patient needs an accelerated initial assessment and management plan. Even today, many trauma patients die in the field or during transport due to airway obstruction or insufficient respiratory support. In trauma patients, especially, an aggressive approach and treatment can save not only the life of the affected patient, but also many other lives through time-conscious treatment. For example, performing cricothyroidotomy, if an airway cannot be secured with oral or nasal intubation within one minute; or, proceeding to central venous or intraosseous access, if a peripheral venous access cannot be established within 90 seconds (59,65,66). In the mass casualty situation, evaluation and management is even more chaotic.

To address this reality, the Newport Beach (California, U.S.A.) Fire and Marine Department, in concert with Hoag Memorial Hospital developed a rapid triage algorithm called "START," an acronym for Simple Triage and Rapid Treatment (92). **The START-triage system can be used by minimally trained lay persons as well as EMS personnel in mass casualty emergencies.** It is not intended to supersede the triage techniques, which are utilized by professional first responders.

Although no randomized controlled trials (RCTs) have evaluated the START-triage system compared to others, it has been used in mass casualty incidents such as train wrecks, bus accidents, and earthquakes. Notably, START triage was utilized at recent U.S. terrorist attacks including the Alfred P. Murrah Building bombing, the first World Trade Center (WTC) bombings, and the 9-11 WTC Attack. The START-triage system is now in widespread use throughout the United States and Canada for Homeland Security teams. As of this publication, START training was underway in the Dominican Republic, Japan, Germany, Switzerland, Africa, and Polynesia.

The START-triage program relies heavily upon gross assessment of respiration, perfusion, and mental status (RPM) as follows: a RR (>30), perfusion as indicated by capillary refill time (<2 seconds), and mental status as determined by ability to follow commands (+/−). Patients who display any of the three worrisome signs (RR >30, delayed capillary refill, inability to follow commands) should be triaged as red "immediate." The mnemonic "RPM 30–2 can do" is taught to help CERT trainees recall the cut-off criteria (Fig. 6). Note that the triage cards displayed previously

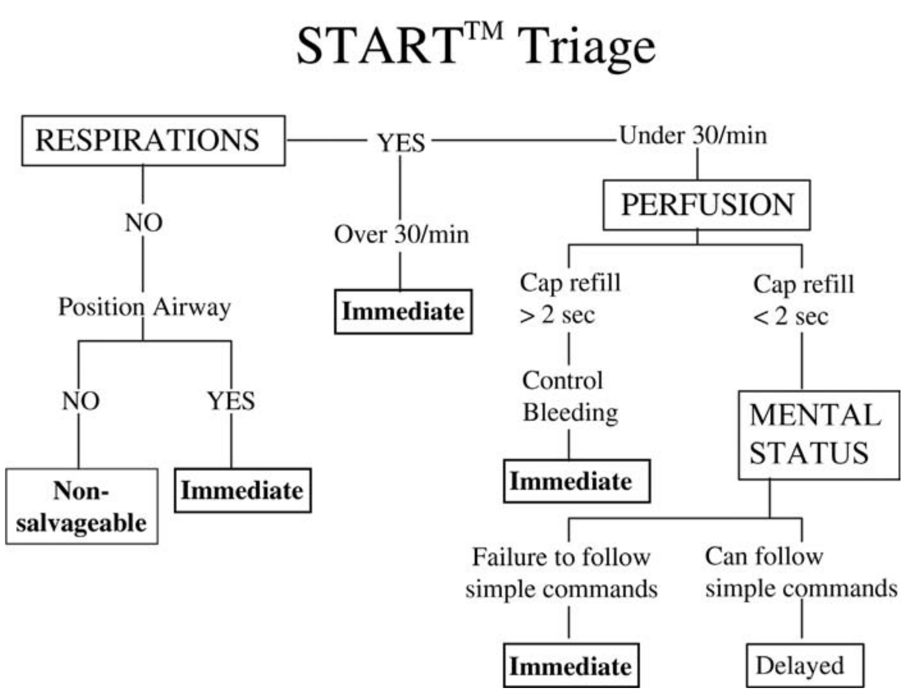

Figure 6 START™ triage algorithm. This algorithm uses three signs to determine the need for immediate ("red tag") transport and treatment (respiratory rate >30, capillary refill <2 seconds, and inability to follow commands).

in Figure 3 utilize the START-triage criteria for designating immediate need for transport and treatment.

START triage separates the injured into four groups, in a fashion (and color code scheme) analogous to that described for advanced triage earlier in this chapter: (*i*) Morgue (black) for those patients who are dead or beyond hope of survival; (*ii*) Immediate (red) for those who can be helped by immediate transportation; (*iii*) Delayed (yellow) for those with minor injuries whose transports can be delayed without jeopardizing outcome; and (*iv*) Minor (green) for those walking wounded level of patients who do not require medical transport or urgent help (Fig. 3A and B).

A pediatric version of START triage, called "JumpSTART" (93), was developed by Dr. Lou Romig in 1995 at Miami Children's Hospital, and updated in 2001. The JumpSTART system allows for modification in children, such as setting normal RR as 15–45 per minute, presence or absence of palpable pulse, and response to pain using the "AVPU" mnemonic (Fig. 7) (93). The "AVPU" system is a commonly used level of consciousness system that stands for Alert, responds to Verbal stimulus or Pain, or Unresponsive.

Nuclear Incidents

Incidents where alpha-, beta-, or gamma radiation is released and humans are contaminated are quite rare, but they have severe and long-lasting consequences (Volume 1, Chapter 39). Three Mile Island (U.S.A.) and Chernobyl (Russia) are memorable examples of these scenarios.

Triage for radiation incidents is complicated because only exposed victims will be initially symptomatic. The vast majority of the irradiated, contaminated, or both types of victims are, initially, asymptomatic. The effects of radiation make these victims de facto "pretriaged," meaning that victims with symptoms are seriously ill, if not beyond therapy.

The triage evaluation should be based upon facts as well as symptoms (51,52). The intensity of radiation is determined by all of the following factors, such as distance from source, duration of exposure, use of PPE, or the presence of protective screens (Table 16). The importance of establishing exclusion zones and PPE for the rescuers has been discussed earlier in this chapter.

The precise level or radiation exposure to alpha-, beta-, or gamma rays can be determined with special measurement devices, called radiometers, also known as "Geiger counters." General triage and zone establishment procedures are also valid in nuclear incidents, the major difference being greater zone ranges. Zone safety ranges for the rescue personnel necessitate the use of personal dosimeters (74). The triage in nuclear incidents utilizes military nomenclature (Table 17) (51,52).

After triage procedures, all the victims must be properly decontaminated and preferably quarantined. All the casualties of a nuclear incident must, despite their triage score during the incident, be continually re-evaluated in a longer postincident phase.

Biological Agent Release

Biological agent release can result from either an act of terrorism or an accidental event (e.g., Sverdlovsk anthrax release). In either case the initial response should include a military liaison. A biological agent released into the environment should be considered a "biological warfare agent-release" (BWA-release) (73–75). In this case military procedures and terminology are used, as the armed forces should take control of the scene upon arrival and thereafter. The procedures employed are the same as for nuclear incidents.

The wide variation of factors involved in biological agent release makes these incidents extremely challenging and stressful. The variety of symptoms and their time

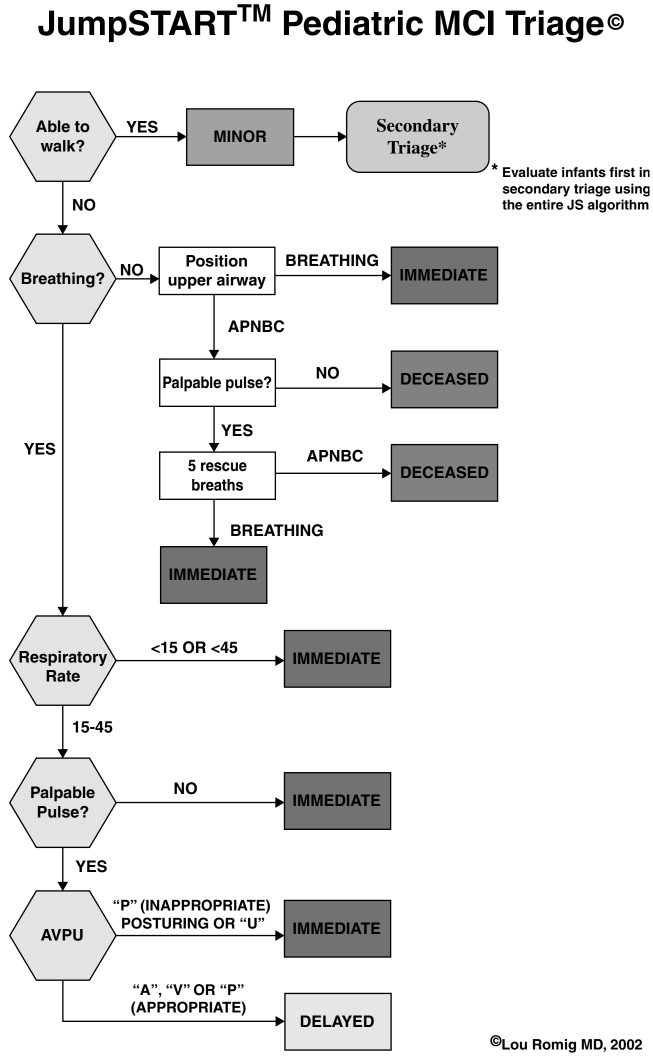

Figure 7 JumpSTART™ triage algorithm. This algorithm is modified from the START triage algorithm to account for the different normal vital signs and verbal, motor, and cognitive abilities of the child. Use JumpSTART if the patient appears to be a child. Use an adult system, such as START, if the patient appears to be a young adult. For children who are unable to walk due to age/developmental status or chronic physical disability, perform JumpSTART triage. If the patient meets "yellow" criteria, examine for significant external signs of injury, such as penetrating wounds, burns, or complex wounds. If present, triage the child as a "yellow" (delayed). If such signs are present and there is uncontrollable bleeding or other indications that the physiological status will deteriorate, triage the child as "red" (immediate). If all worrisome signs are absent, triage the child as "green" (minor).

Table 16 Intensity of Radiation Exposure: Physical Factors and Use of Personnel Protective Equipment

Factor	Comments
Distance	Short distance to the radiation source results in large amounts of various types of radiation (alpha, beta, and gamma).
Duration	Short exposure to relatively high doses of radiation is often less damaging than a longer exposure to lower doses.
Use of PPE	Appropriate PPE use can prolong the duration of stay in a contaminated environment and lessen the effects of the exposure.
Presence of protective screens	Protective screens can isolate the effectual amount of radiation and lessen its effects.
Type of radiation	Alpha radiation of 8 MeV energy can have a track length in air of c. 7.3 cm (2.8 in.), beta radiation 34.4 m (112 ft 10.3 in.). Gamma radiation can penetrate up to 40 cm (1 ft 3.7 in.) of solid lead and has a track length in air of several kilometers.
Area of irradiation (internal and external)	Contamination is typically external (whole body or partial), but may be internal (e.g., drinking contaminated water) or both (e.g., near drowning in contaminated water).

Note: See Volume 1, Chapter 39, for greater description of personnel protective equipment subcategories A, B, and C.
Abbreviation: PPE, personnel protective equipment.

span, the need for treatment and isolation (hospital capacity), personnel safety, patient outcome (mortality and morbidity), political and general public safety issues, must all be taken into consideration during the triage procedure.

Asymptomatic casualties may manifest symptoms days or weeks later, leaving the triage officer with an unavoidably incomplete evaluation of the incident and the triage task at hand (73). All symptomatic casualties fall under military triage procedures (see section "Nuclear Incidents"). An aggressive approach (if enough resources available) can be life-saving in certain cases.

All asymptomatic victims can be green-coded, but must remain under observation for a specific period of time defined for the presumable illness that would result from the specific exposure. Antidotes play a smaller role in biological agent release on account of their limited availability (73). However, these should be administered as quickly as possible when exposure and antidote are both known and available (Table 18). Casualty decontamination is rarely needed, but the high degree of potentially contagious material calls upon the use of special PPE by the rescue forces, and a strict quarantine regimen in selected hospitals (74).

The establishment of exclusion zones is essential. The absolute exclusion for nonaffected civilians should be expanded to the cold zone, which in these cases can cover a very large geographic locality (59,72).

More recently, after the anthrax attacks in the United States, special detection devices have been introduced onto the market, aimed at detecting biological agent leakage. These devices are called "biodetectors," and can detect biological agents with acceptable precision margins.

Chemical Agent Release

These incidents can occur as industrial disasters (Bhopal, Seveso), or as the result of a terrorist act (Tokyo subway Sarin attack). No clear differentiation exists between chemical exposure following industrial disasters, or military use, or acts of terrorism. Many substances used in the chemical industry are classified as chemical warfare agents, or have similar effects (81).

Chemical agents (CA) are characterized by various physical properties (73), which help quantify their effects on humans: (*i*) persistency, the amount of time a liquid agent remains fluid. In this form, it can fully deploy its effects on humans; (*ii*) volatility, reversibly proportional to its persistency; (*iii*) boiling point, proportional to the persistency of the agent; and (*iv*) solubility in water, or other solvents.

The common CAs are easily detected in the environment. Detection methodology ranges from simple use of special papers (e.g., military M8 and M9 papers), to the very sophisticated and expensive technology such as mobile or portable chemical labs. The latter are not necessarily limited to the military, as most major fire departments in developed countries have mobile CA detection units. These mobile detection labs facilitate the tasks of the medical team and especially of the triage officer, as soon as the type of agent is determined (73,74).

The clinical effects of CA depend on: (*i*) the concentration of the agent in the environment; (*ii*) the specific

Table 17 Triage Nomenclature and Classifications for Nuclear, Biological, and Chemical Exposure

Triage category	Definition/comments
T1 (red)—immediate treatment	The victims' condition is serious, vital functions are jeopardized, and life-saving actions must be imposed. Survival chances are good.
T2 (yellow)—delayed treatment	Victims need treatment. Their condition is not life threatening, but on-site stabilization is needed.
T3 (green)—minimal treatment	Slightly injured (irradiated, contaminated) or noninjured victims, needing minimal treatment.
T4 (green)[a]—expectant treatment	Expectant treatment (T4): severely injured victims, no realistic chance of survival. Only palliative treatment on site to lessen suffering is needed.
T5 (black) Dead	A physician must always certify death.

[a]In military setting dark blue is often used for "expectant treatment."

Table 18 Most Important Biological Agents and Their Corresponding Antibiotic Treatments or Chemical Antidotes

Biological agent	Disease	Field decontamination[a]	Antibiotic or antidote
Bacteria			
Bacillus anthracis	Anthrax	Standard	Ciprofloxacin, doxycycline
Brucella melitensis	Brucellosis	Standard	Doxycycline, rifampin[b]
Coxiella burnetti	Q fever	Standard	Doxycycline
Francisella tularensis	Tularemia	Standard	Doxycycline, ciprofloxacin
Yersinia pestis	Plague	Mask protection of coworkers	Streptomycin, gentamicin, doxycycline, chloramphenicol, ciprofloxacin
Virus			
Arenavirus	Lassa fever	N95 respirators	Ribavirin
Filorvirus	Ebola	N95 respirators	Supportive care
	Marburg	N95 respirators	Supportive care
Hanta virus (related to Ebola)	Hantavirus pulmonary syndrome	N95 respirators	Ribavirin (under experimentation)
Variola major	Smallpox	N95 respirators	Cidofivir, supportive
Numerous viral agents	Viral encephalitis	Standard	Virus specific agent
Toxins			
Clostridium botulinum	Botulism	Standard	DoD heptavalent antitoxin, FDA bivalent antitoxin, supportive
Staphylococcus aureus enterotoxin B	Staph poisoning (toxic shock)	Standard	Vancomycin
Ricin (from castor beans)	Ricin intoxication	Standard	No known antidote; supportive care

[a]Standard field decontamination is water shower of patient and use of gloves, gown, hand washing of coworkers. With airborne pathogens, the hospital workers should wear a N95 respirator and the patient should be isolated.
[b]Combination therapy recommended.
Abbreviations: DoD, Department of Defense; FDA, Food and Drug Administration.

amount of agent needed for a biological effect; (*iii*) persistency of the agent on the surface in question; (*iv*) temperature and humidity of the environment; and (*v*) the duration of sunlight acting on the released agent (see Volume 1, Chapter 39) (76–80).

Two specific triage precautions must be observed during response to CA release incidents (75–77): (*i*) Rescue force protection: it is often difficult to identify the CA release during the initial minutes of an event, and this release can develop into a serious hazard for the first police and rescue forces to arrive on-site; (*ii*) Victim exposure: victims exposed to CA contamination may show a variety of symptoms. Syndromic surveillance has been promulgated in recent years in order to detect surreptitious chemical agent releases. Symptoms can be somewhat delayed, and the victims may not directly relate them to the exposure. This phenomenon can have a severe spillover effect, particularly if the patient is brought into the hospital without having undergone decontamination procedures before entering, and thus potentially resulting in cross-contamination of the hospital healthcare workers.

In a terrorist attack where chemical warfare agents are used, all triage problems are magnified. In such an event, chemical agent detectors are required. The old-fashioned agent indicator matrix (AIM) tools are less useful because of the time required to determine the agent. The AIM technique utilizes a chart to determine the type of agent released, depending on the symptoms exhibited by an unprotected patient (73).

In CA release, it is obligatory to establish the three exclusion zones. Decontamination is always advisable (as in gas exposure), if not absolutely necessary (as in liquid, aerosol, and vapor). The initial decontamination should take place in the warm zone (73).

Victims with symptoms after exposure to CA should be triaged according to the severity of their symptoms, with cardiopulmonary and central nervous system (CNS) being more serious (73,74,79). Those with involvement of the upper or lower respiratory tract should be coded red. Slight or medium respiratory tract symptoms can quickly evolve into severe respiratory insufficiency within minutes, and should be approached and treated aggressively.

It is not advisable during a mass triage to attempt resuscitation of normothermic CA victims who have had no heart rate or breathing for an indefinite time period. Resuscitation is advisable if the cardiac arrest is witnessed, or the patient is thought to be hypothermic prior to an arrest of brief duration, and resuscitation can begin immediately under safe conditions for the rescuers (73). Environmental safety considerations should always be evaluated before any action is taken by the rescuers following CA exposure.

Victims with little or no CNS involvement should be coded yellow, but are potentially red, and not green-coded. GCS <15 should be coded yellow. GCS <12 and all those victims with at least one seizure should be coded red, because the gradual affection of CNS involvement is continuous, and ends in death if untreated.

Antidotes (see Volume 1, Chapter 39) should be administered immediately if available. The decision to administer antidotes to patients with minimal or no symptoms should be made based on the size of the incident and the availability of antidotes. If significant numbers of patients are expected, the risk of running out of antidote could mean that some patients more in need of antidote later on in the triage may not get it. All victims treated with antidotes should remain in the red-coded area until admission to the hospital, as all antidotes have a short-lived effect that requires monitoring and may require redosing. It is not advisable to bring expensive monitoring equipment into the red zone (unless an abundant supply is available for use in the noncontaminated areas as well), as such equipment may not be able to be adequately cleaned of the CA.

Supportive measures should be instituted immediately as needed. Airway, breathing, and circulation must be secured and high-flow oxygen administration is always indicated. **Severely contaminated victims can exhale large amounts of the CA, often enough to contaminate and affect the rescuers.** The use of PPE and application of special filters if available for the respirator and the resuscitation equipment is always mandatory in these cases (78,79).

Pediatrics

Triage in pediatric patients represents many practical, evaluation, and communication-related problems. In some cases, the child can withstand a greater anatomical or physiological insult and permanent damage than the adult, while in others cases the child is more vulnerable. This leads to many more and prolonged cases of resuscitation in children compared to adult resuscitation. Black triage tags are only given to children after substantial resuscitation, or in clear cases, or futile resuscitation (e.g., decapitation), but the basic triage principles and procedures are nevertheless the same as for adults (91).

War

War is even more complicated than civilian practice in terms of triage procedures. The need for triage collides with the hazards present, the medical ethics of military procedures, and ultimately, the political and military goals (51,52).

In peacetime, the aim of civilian triage is to save the lives of as many victims as possible, following appropriate restrictions with respect to the rescuers' safety. During war, an important secondary aim of triage is in returning a wounded individual back to a useful combatant status (41). This is part of the concept termed, "reverse triage."

Thus, triage procedures and main goals are differentiated: (*i*) In war, the triage may be more gross, often subjugated to many aspects other than primary rescue purposes; while in civilian incidents, triage is more accurate and detailed with the simple aim being "the greatest good for the greatest number." (*ii*) Another important difference is the direction of evacuation, which is radial and multi-directional in peacetime (even cross-border evacuation), while during war, it is usually only linear and most often only unidirectional (59). (*iii*) Finally, the triage officer must comply with standard operating procedures (SOP), and remain fully cognizant of the resources and lines of evacuation to higher levels of care.

EYE TO THE FUTURE

The individual response to injury is complex and difficult to model adequately. It is therefore valuable to continuously use several, albeit imperfect, injury severity scoring systems. On account of their frequent uses in outcome models, the scoring systems are scrutinized for inaccuracies that could affect outcome validity. In this process, trauma registries are increasing in volume and numbers, hopefully yielding more precise models. However, this will only happen if a focus remains on validation of data. Significant resources have, unfortunately, been spent collecting inapplicable data, and more importantly, far too few resources and focus have been put on prophylactic measures.

The outcome probability methods are predominantly based on sophisticated statistical models, capable of controlling for wide case-mix differences, and strengthened through data volume and inclusion of newer important parameters such as age (break down) and comorbidity.

As data become more uniform through improvement of scoring systems, additional mathematical tools such as neural networks or pattern recognition systems analogous to those used in chemometrics or econometrics could become applicable (89).

Triage will also adjust and progress through technological advances designed to improve and facilitate communication and transport. Technical and medical research must bring devices and improved treatment methods to the field in order to facilitate triage and improve patient care. Finally, more emphasis and financial investment must be placed on educating personnel.

A system of life saving clinical maneuvers for the management of toxic exposure was developed by Trauma Care International (ITACCS). Toxic Advanced Life Support™ (TOXALS™) prioritizes contamination control and decontamination of the patient, in concert with the treatment of the most life-threatening injuries first. TOXALS has now been accepted into chemical-biological (CB) response planning in France, the United Kingdom, and elsewhere (94,95).

It is also anticipated that TOXALS will proceed to the next level, which would be a full training program similar to Advanced Cardiac Life Support® (ACLS®), Pediatric Advanced Life Support® (PALS®), and ATLS. In this expanded version, TOXALS training would combine didactic instruction, laboratory sessions, and field exercises to train medical personnel in the management of casualties exposed to chemical, biological, or radiological agents.

Didactic instruction would include review of the known toxic chemical, biological, and radiological agents in terms of their physical characteristics, as well as the pathophysiology, diagnosis, and treatment. Additionally, the principles of field management, including triage and decontamination of exposed casualties, should be taught.

Laboratory training could involve hands-on experience by participating in the resuscitation of a laboratory animal exposed to a nerve agent proxy. The field training exercises should provide experience in the proper use of personal protection equipment, detection, and triage of contaminated casualties, as well as the treatment and decontamination of exposed casualties. The students should also be trained in basic military operations involving toxic exposures so they can interact more effectively with these military teams.

In the United States, a 2-day, 16-hour Advanced HAZMAT Life Support Course is offered by the University of Arizona Health Sciences Center (96). In 2005, the course was approved by the Office of Domestic Preparedness (ODP) and its funding can be sought to cover the tuition fees.

Other innovations evolving in the triage arena include: (*i*) advanced computerized manikin modeling for disaster life support scenarios and patient simulations; (*ii*) Basic and Advanced Disaster Life Support courses have been developed at the University of Georgia, and are managed by the National Disaster Life Support Foundation (97); (*iii*) the development of a "Smart Triage" disaster tag has been ongoing at the University of California, San Diego and at the University of California, Irvine, in conjunction with Qualcomm and $CalIT^2$. This project incorporates wireless network technology with GPS, bar coding, and vital sign monitors to allow patients to be tracked and monitored at a disaster site (also see Volume 2, Chapter 72). The technology can also be used for responders at a disaster site to track and locate responders, and to facilitate and direct search-and-rescue operations to those secondary victims with vital signs should a secondary event, such as a building collapse, occur, involving first responders.

SUMMARY

Trauma scoring and trauma registries are defined and established in modern trauma systems. They have shown their worth through the resultant improved quality of care and increased patient survival, but are still not able to accurately predict individual patient outcome. The scoring methodologies are applicable in most settings, but can be difficult to comprehend on account of complex statistics. When in doubt, it may be wiser to choose a simpler trauma scale and system.

The greatest current issue in trauma scoring systems is the need to quickly evolve to the point at which the data gathered from an incoming patient is automatically compared in "real time" with an existing large-population database, thereby resulting in a number of immediate directives. These directives emerge as prognosticating information is calculated about survival, morbidity, and return to function. Additionally, these more immediate data renderings can be of assistance in rationalizing care and improving allocation of scarce resources.

Current triage procedures are, basically, the result of the individual triage officer's experience and education, combined with the capabilities and limitations of the trauma system. Local and regional adaptation within this system can strengthen regional patient outcomes. However, regionalization impedes universal consensus and thereby weakens efforts to improve national and international uniformity of triage. These considerations must be taken into consideration when deciding which methodologies to apply in a trauma system.

KEY POINTS

- Trauma scoring is a useful tool for: (*i*) triage and prehospital treatment, (*ii*) documentation using common terminology, (*iii*) injury severity description, (*iv*) quality of care and patient outcome evaluation, (*v*) trauma system evaluation and comparison, (*vi*) trauma epidemiology, research, and funding.
- Anatomical scoring is less useful than physiological data for triage decisions; it is more predictive when used in combination with physiological parameters for quantifying outcomes.
- The GCS correlates with clinical outcome when used in isolation, as well as when combined with other physiological scoring systems.
- The pediatric trauma score (PTS) is useful and accurate for the physiological and anatomical differences unique to pediatric patients.
- The TRISS method predicts trauma patient outcomes on the basis of their injuries and enables comparisons of patient outcomes among trauma systems while controlling for differences in injury severity.
- Triage is a process for categorizing victims involved in a multi-casualty incident or disaster into different degrees of severity, and assigning appropriate graded treatment and transport priorities.
- Triage is a dynamic process, with reclassification of status possible after the transport and definitive treatment of the victim has occurred.
- The main goals of triage procedures are to (*i*) prevent avoidable deaths, (*ii*) ensure proper initial medical treatment within a minimal time frame, and (*iii*) avoid misusing assets on hopeless cases.
- Triage should be applied whenever the number of patients exceeds the capabilities of the available resources (medical personnel and equipment) at the local level.
- During the initial triage, patients are assigned a "treatment priority."
- The triage priority is identified by a color-coded triage tag, although the color code and triage subsections (categories) are not universal.
- A yellow-coded victim can rapidly deteriorate to red-coded status, just as a red-coded victim can improve to a green-coded status. The fluidity of triage continues until definitive treatment of the victim occurs at the hospital.
- Decontaminated zones must be uphill, upwind, and upstream from the previous contaminated zone.
- The predetermination of adequate medical supplies and logistics support in mass casualty incidents and disasters requires an accurate forecast of incoming injuries and associated influencing factors.
- Communication is essential for any operation. The quality and quantity of the local telecommunication must be wisely distributed among the rescue forces.
- The START-triage system can be used by minimally trained lay persons as well as EMS personnel in mass casualty emergencies.
- Triage for radiation incidents is complicated because only exposed victims will be initially symptomatic.
- Severely contaminated victims can exhale large amounts of the CA, often enough to contaminate and affect the rescuers.

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Resuscitation Suite and Operating Room Readiness

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INTRODUCTION

Most modern trauma centers have one or more trauma resuscitation suites (TRS) in or near the emergency department (ED) and at least one dedicated trauma operating room (OR), which remains reserved for patients requiring emergency surgical intervention (1). This chapter describes the preparation and readiness requirements needed for both the TRS and the trauma OR in order to be fully capable of receiving and managing critically injured patients. In addition, this chapter briefly summarizes the monitoring considerations important for transporting trauma patients from the TRS to the radiology department or to the OR (see also Volume 1, Chapter 7).

This chapter also provides insight into both civilian level I trauma center requirements as well as military guidelines for TRS and OR preparedness. In this regard, terminology and equipment utilized by the U.S. military and other North Atlantic Treaty Organization (NATO) countries will be reviewed. Several of the specific organizational schemes used by NATO military medical teams are provided along with examples of military facilities currently deployed in Afghanistan and Iraq. Because there are differences in terminology and equipment used by various branches of the military and between countries, not all examples could be provided. This book provides examples and figures utilized by the U.S. armed forces.

The medical priorities for civilian and military units are similar; however, military teams need to manage casualties with far fewer resources compared to their civilian counterparts. In addition, military crews must be trained and capable of rapid mobility and deployment. Examples of both civilian and military TRS and trauma OR readiness will be provided, along with the basic elements required to assure preparation for incoming patients. **Organization and preparedness, along with clear communication and expert support from all members of the multidisciplinary trauma team, constitute the keys to success in trauma resuscitation.**

PHYSICAL PLAN OF TRAUMA RESUSCITATION SUITE

The physical layout of the TRS should allow easy access from the ED ambulance entrance and the helicopter landing pad. The configuration should also be conducive to patient transport between the radiology suite, the OR, and the surgical intensive care unit (SICU). Most level-I trauma centers have several patient management cubicles within the TRS which are usually referred to as "Trauma Bays."

A model physical layout of a typical civilian trauma bay is shown in Figure 1. An overview of the TRS at a level-I trauma center is shown in Figure 2A and B. Note the trauma resuscitation bed in the center; a built-in imaging unit hangs from the ceiling above in Figure 2A (not shown in Fig. 2B), a portable ventilator is at the head of the bed on standby, while oxygen (O_2) can be applied by mask from the head of the bed. Also at the head of the bed is the monitoring display, clearly visible to the team members; large, color-coded displays allow everyone involved to be aware of the patient's pulmonary and hemodynamic status.

In the background is the workstation located at the head of the trauma bay, immediately behind the physician running the trauma resuscitation. The workstation table contains the portable telemetry/pulse oximeter monitor, on standby, but ready for use; allowing easy transfer of leads from the fixed monitor on the wall to the portable monitor facilitates moving the patient, once stabilized, off the table and out of the trauma resuscitation room. On the right side of the screen are radiographic viewing boxes, shown in Figure 2B, along with digital imaging screens (not shown). An intravenous (IV) pole with prepared resuscitation fluids and lines is seen in the right background; fluid warmers and rapid infusion devices are nearby, but not shown.

The physical plan of the TRS and adjoining areas should also be conducive to temporary expansion in times of disaster or other emergency, allowing for a large influx

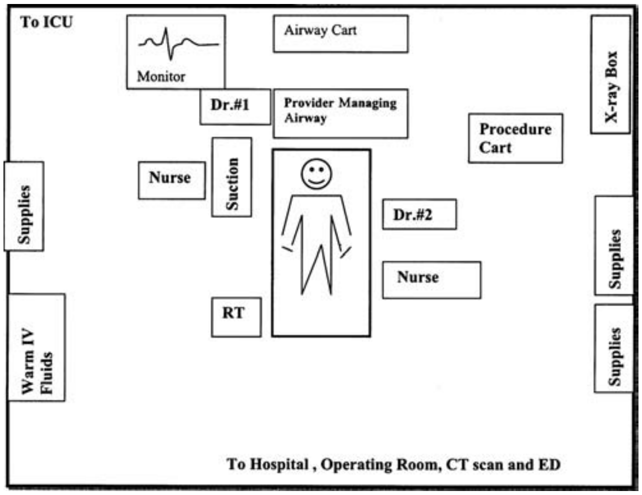

Figure 1 Schematic drawing of a trauma bay within a typical civilian trauma resuscitation suite. The patient is located central to monitoring and diagnostic equipment. There is easy access and close proximity to the hospital operating room, CT scanner, remainder of the emergency department, and the SICU. Basic radiology capabilities are available within the TRS itself.

of patients. This is generally accomplished by conversion of nearby patient care areas into additional "trauma bays" as the need for patient care areas increase. For example, in the event of massive casualties, the postanesthesia care unit (PACU) and other patient-holding areas can be converted into shock-and-trauma resuscitation and triage sites; in this case, each of the normal recovery room stations is converted into fully functional trauma bays. These same converted sites can serve the role of PACU after emergency surgery as well. All modern trauma centers should have a prepared disaster plan to facilitate this type of expansion in case of emergency.

The physical characteristics and standardized layout for a trauma bay as approved for NATO forces (including U.S., British, Australian, Italian, Portuguese, German, and French armies, etc.) is shown in Figure 3. **The configuration of the NATO trauma bay is arranged according to a predefined plan so that physicians, nurses, and medic assistants from different countries will know where items are expected to be located.** Although intermingling of national military corps is rare, and a potentially disastrous practice, this can occur when a mass casualty emergency arises. In civilian practice, trauma bays are often set up in accordance with local practices of anesthesiologists, ED physicians, and trauma surgeons, and hence there is great variability between institutions.

When multiple trauma bays are to be prepared in a military setting, the configuration shown in Figure 3 is duplicated in "cookie cutter" fashion, allowing several trauma bays to be located side-by-side and, when space allows, trauma bays are arranged on both sides of large temporary structures erected by the medical corps (Fig. 4). Occasionally, these sites must serve multiple roles, including TRS, trauma OR, and temporary PACU/SICU (as discussed later).

Regardless of the venue (military or civilian), the lifesaving resuscitation equipment requirements are essentially the same, although the quantities and varieties of emergency equipment available in the military setting are somewhat less abundant that that generally available in civilian settings. The smaller supply inventories characteristic of military facilities is mainly based upon minimizing transport weight, thus decreasing the time required for set up and breakdown and maximizing mobility. The various types of equipment, drugs, and other supplies needed for the TRS are reviewed next.

Equipment

Essential equipment and supplies should be organized and readily available in the TRS. Excessive cluttering of equipment should be discouraged. The physical plan of the TRS should allow easy access to additional equipment as needed.

In most trauma centers, commonly used items are organized into separate carts with clear labeling for speedy access. The various categories of supplies usually include: (*i*) an airway cart, (*ii*) a surgical procedure cart, (*iii*) an IV access cart, and (*iv*) a cart for other miscellaneous items. In military settings, all the equipment must fit into specialized transport trunks, prelabeled and sized to contain only the bare necessities.

Airway Cart

The airway cart is often divided into two compartments: one for conventional airway management and the other for difficult airway situations. Basic airway equipment (Fig. 5) includes a regulated O_2 source, suction apparatus, endotracheal tubes, laryngoscope, mask, airway adjuncts, and a bag-valve-mask (BVM) ventilation device. These items should be setup and ready to go at each trauma bay within the TRS. Special airway equipment for unusual or difficult intubations and a small "transport capable" ventilator (Fig. 6) should be in place and functional. Appropriate size equipment in each category should be readily available for pediatric trauma patients. The basic airway equipment items necessary for an emergency trauma airway cart (ETAC) are summarized in Table 1. The trauma anesthesiologist will decide the optimum method for establishing a definitive airway (as discussed in Volume 1, Chapter 9).

Procedure Cart

Aside from endotracheal intubations, the procedures that are commonly performed in the TRS include the insertion of large-bore peripheral venous catheters, chest tubes, central venous catheters, arterial lines, nasogastric tubes, and bladder catheters. The essential supplies for these procedures can be stored in a separate cart. Prepackaged sterile supplies are prepared ahead of certain procedures, for example., venous cut-down, thoracostomy tube insertion, diagnostic peritoneal lavage, thoracotomy, ventriculostomy, and so on. The trauma procedure cart should be checked on a daily basis for inventory and replacement of supplies used. Some centers will utilize separate carts: one for surgical procedures (Fig. 7) and one for IV access lines and tubes (Fig. 8); in other centers, these will be combined. In a military setting, these items are prepositioned in standardized pouches and placed on the walls of the resuscitation tent (Fig. 3).

Monitors

The basic monitors include electrocardiogram (ECG), manual and noninvasive blood pressure (NIBP), pulse oximeter, thoracic impedance for respiration rate measurements, and temperature (some of this equipment is visible in Fig. 2A). Disposable carbon dioxide detectors are essential

(A) (B)

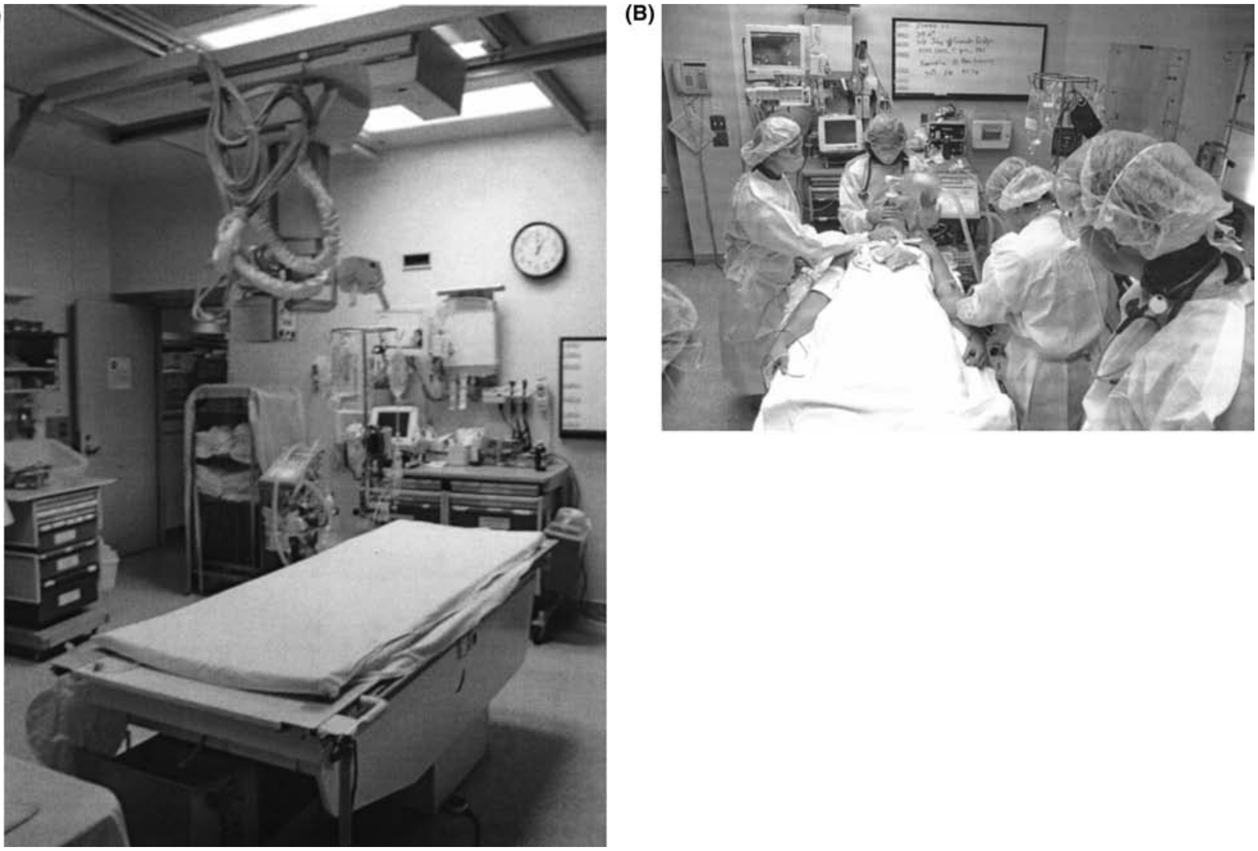

Figure 2 (**A**) Trauma Bay #1 in the trauma resuscitation suite at the University of California San Diego (UCSD) Medical Center. Note the trauma resuscitation bed/imaging table in the center, the built-in overhead imaging unit hanging from the ceiling, a portable ventilator on standby, a telemetry/pulse oximetry monitor, a crash cart over to the side, and a scrub area. Also note close proximity to the surgical intensive care unit seen through the open door in the far left corner of the image. (**B**) View of patient in Trauma Bay #2 at the UCSD Medical Center trauma resuscitation suite. The "MIVT" board is in the background showing mechanism and initial vital signs. The team leader is at the head of the bed applying oxygen with the assistance of a bag-valve-mask device, while an assistant applies cricoid pressure with the cervical collar still in place. After the intravenous line is placed (left arm of patient), a helper will apply and maintain in-line immobilization of the neck, and the collar will be removed prior to intubation (not shown). The trauma team members are gowned and gloved (i.e., adhering to universal precautions) and wearing lead vests underneath the protective gowns. In the background (at the head of the patient) are monitors (mounted with current vital signs) along with a transport monitor, which will be used to accompany the patient during transport to the CT scanner, operating room, or surgical intensive care unit (as needed). In addition, a transport ventilator (to left behind patient) is available if needed (Fig. 6).

to verify proper placement of the endotracheal tube. Optimum resuscitation and invasive monitoring of trauma patients requires that the TRS be stocked with an adequate supply of large-bore IV catheters, central lines, and arterial lines to facilitate rapid placement of the lines for volume resuscitation and for monitoring. Although retrospective data have shown that arterial lines inserted in trauma while the patient is in the TRS have higher complication rates (including infections) than those placed subsequently and under more controlled and sterile circumstances (3), arterial lines are recommended during the initial resuscitation of critically injured patients. Accordingly, use of aseptic techniques should be emphasized and materials readily available to help keep the field clean, without delaying care.

Immobilization Devices

Splinting of extremity injuries and binders for stabilization of pelvic fractures are required to minimize pain and reduce blood loss. Likewise, cervical spine (C-spine) collars should be available to place on patients who may not have had one placed in the field, or for those who have soiled or damaged their devices. Sterile Steinman pins (for use in pelvic, acetabular, and femur fractures) should be immediately available, along with the required drills, and traction devices.

Specific types of splints will be required for different categories of fractures. Malgaigne equivalent fracture-dislocations of the pelvis and acetabular fractures should be immobilized with distraction pins placed in the distal femur (as long as that too is not fractured); fractures of the femur should be immobilized with a traction pin placed in the proximal tibia (unless fractured). While radiographs are being taken, temporary traction splints are useful and should be available in the TRS.

Temporary stabilization of the pelvis may be achieved by wrapping a bedsheet or applying a fabric belt around the fractured pelvis (see Volume 1, Chapter 28). Commercially available knee immobilizers should be available in the TRS for stabilization of knee injuries. Different size cardboard or

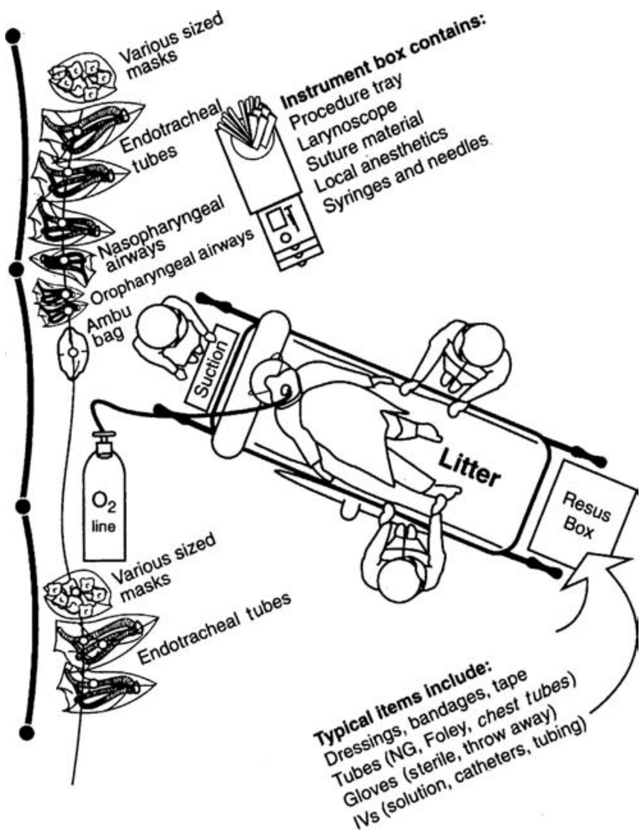

Figure 3 Trauma bay setup within a military trauma resuscitation suite (TRS)/operating room (OR). As per NATO guidelines, in military settings the TRS may also need to serve as the trauma OR in certain geographic areas and under certain conditions. In this figure, the anesthesiologist is at the head of the bed and the trauma physician and assisting corpsman (technicians and nurses) are on the sides. Airway equipment is arranged along the tent wall behind the patient. Resuscitation equipment (e.g., chest tubes) is at the foot of the stretcher. Surgical supplies are not shown. *Source*: From Ref. 2.

plastic splints can be used for leg or arm fractures. Bulky dressings made out of sheets or pillows will prevent the development of pressure sores over bony prominences in patients with ankle fractures. All material for immobilization should be clearly labeled according to size and be readily available in the TRS, preferably on an orthopedic equipment cart.

Other Equipment

Other essential equipment include: (*i*) moveable lighting systems; (*ii*) fluid and blood warmers with functional thermostat and a rapid infuser system; (*iii*) a large supply of sterile and nonsterile gloves; (*iv*) blood-sampling tubes for type and cross, arterial blood gas, and assay of coagulation factors; (*v*) storage cart for IV fluids, and sterile as well as clean supplies (e.g., gowns and additional gloves). Easy to identify, "sharps" disposal containers should be located in various easy access areas of the TRS. To best utilize the time under acute trauma conditions, much of the equipment and supplies should be assembled beforehand. **Whenever multiple trauma bays are located within the same TRS, each one should be set up in a similar (optimally identical)**

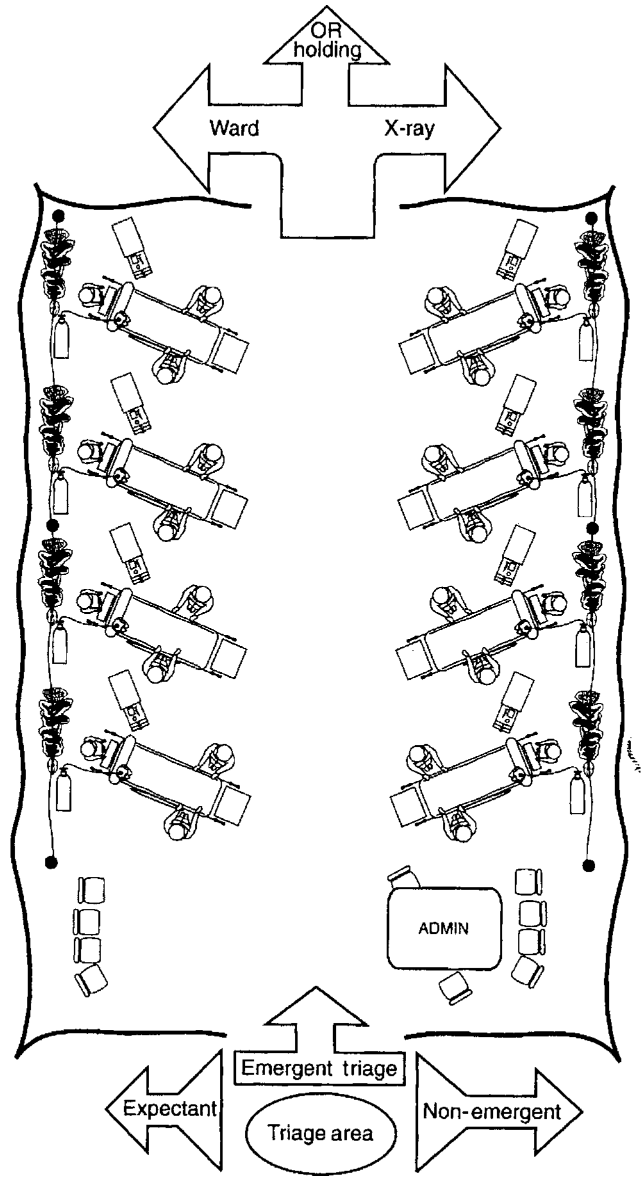

Figure 4 Multiple trauma bay array as per NATO guidelines. The figure shows eight trauma bays within a large trauma resuscitation suite (TRS) tent. Each trauma bay is set up in a fashion identical to that illustrated in Figure 3. In ideal situations, this multi-bay TRS would be used for resuscitation evaluation and triage of severe casualties, who would then proceed to specific operating rooms, to radiology, or to the surgical intensive care unit (SICU). However, if there is a major influx of mass casualties, these trauma bays will need to serve as operating rooms and, occasionally, as postanesthesia care units and/or temporary SICUs as well until the peak flux of patients wanes. *Source*: From Ref. 2.

fashion. Uniformity helps to minimize the time spent by practitioners becoming oriented in their surroundings and/or searching for life-saving equipment or drugs.

Pharmacologic Agents

A variety of pharamacologic agents may be required during the initial management of the trauma patient. Etomidate and succinylcholine (or rocuronium) are the most appropriate

Figure 5 Trauma airway equipment. The basic and advanced airway tools needed for emergency trauma airway management are contained within the code bag (background). The items needed for intubation (laryngoscope with various blades, stylets, and endotracheal tubes) of various sizes, as well as tools to assist ventilation [oral and nasal airways, bag-valve-mask (BVM) ventilation devices], suction, and oxygen tubing are all prepared ahead for easy access. Induction and resuscitation drugs as well as materials for awake intubations as well as emergency airway aids (laryngeal mask airways, esophageal-tracheal combi tubes, etc.) are contained in separate compartments. Tools to confirm endotracheal position of the ETT (e.g., end tidal CO_2 detectors and esophageal detector devices) are also mandatory. A surgical airway (e.g., cricothyroidotomy) kit should also be included. However, an additional dedicated cricothyroidotomy–tracheostomy tray should be available in the trauma resuscitation suite.

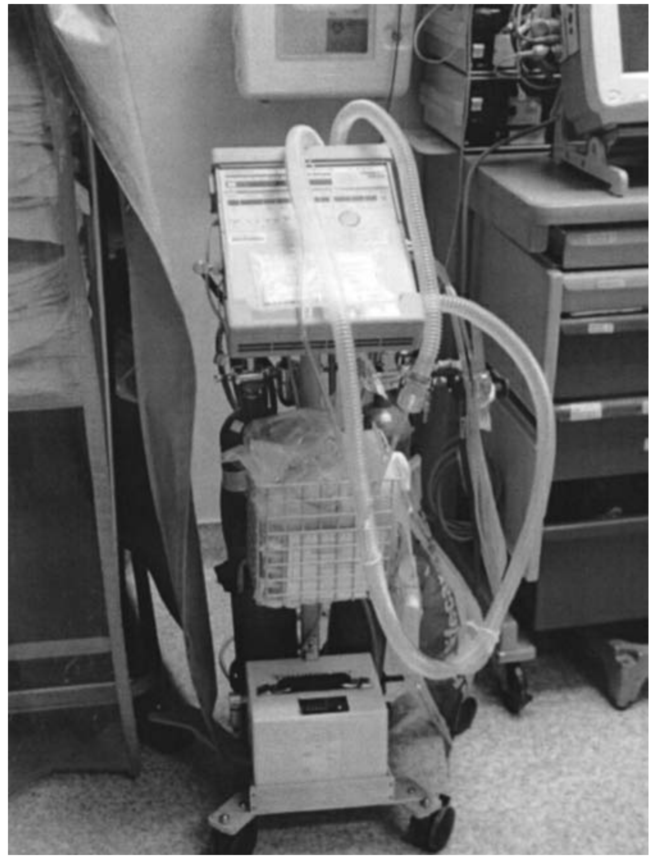

Figure 6 Transport ventilator. The key elements of a transport ventilator include reliability, simplicity, portability (i.e., battery powered) and durability (can take abuse). The transport ventilator shown in this figure, the Pulmonetic Systems LTV 1000 (Minneapolis, Minnesota, U.S.A.), has been in continuous use for three years at the UCSD Trauma Center. The device is capable of ventilating a patient for six to eight hours on a full battery charge. However, the two "E" cylinder O_2 tanks only provide flow for about 45 minutes. Longer periods of use require an external O_2 source or changing the O_2 cylinders. The device can deliver volume control or pressure control and provide positive end expiratory pressure (PEEP) with flows up to 100 L/min (higher flows on tanks will result in less time between the need to replace the O_2 "E cylinder").

drugs for rapid sequence induction (RSI) in the majority of trauma patients (see Volume 1, Chapters 8, 9, and 19). These as well as other routine anesthetic drugs (often required after stability is achieved in trauma patients) should be readily available in prelabeled and dated syringes. Easy access to the hospital pharmacy is necessary for some of the less commonly required drugs (e.g., recombinant factor VIIa, DDAVP®, etc.).

Computerized order entry and/or utilization of a central tube system can expedite procurement of infrequently used drugs in large institutions. A "crash cart" containing all emergency drugs and devices used in Advanced Cardiac Life Support® (ACLS®) and or Advanced Trauma Life Support® (ATLS®) must be readily available.

Supplemental controlled substances are often locked in nearby cabinets (which members of the trauma anesthesia team must have access to). A computerized drug delivery system (e.g., Pyxis®) works well in many places for less frequently used items. However, drugs and equipment that might be required in an emergency should never be placed in a system that does not allow immediate accessability. Some of the pharmacologic agents commonly used during trauma resuscitation are listed in Table 2.

Communication

The TRS can be a high-stress environment in which resuscitation decisions need to be made expeditiously and often with dynamically changing priorities. The importance of clear communication among the trauma team members cannot be over emphasized. **An essential component of trauma OR and TRS preparedness is the establishment of a robust communication system with clear lines of correspondence throughout all stages of management.**

Table 1 Airway Supplies—Essential on the Emergency Trauma Airway Cart

Conventional airway equipment	Difficult airway equipment
Airway adjuncts	LMA
Oral airway	Disposable
Nasal airway	Intubating
Esophageal obturator	ETC
Pharyngotracheal	Fiberoptic bronchoscope
Laryngoscope	Fiberoptic laryngoscope
Straight blade (Miller)	(e.g., Bullard
	laryngoscope)
Size 2 and 3	Cricothyroidotomy kit
Curved blade (McIntosh)	Light wand
Size 3 and 4	Retrograde kit
Endotracheal tubes	
Sizes: 5.0–8.0 mm	
Malleable stylet	
Bag-valve-mask	
Different size masks	
$P_{ET}CO_2$ detector device	
Esophageal detection device	

Abbreviations: ETC, esophageal tracheal combi tube; LMA, laryngeal mask airway.

Figure 7 Invasive procedure cart. Seen here is a cart that holds various trays containing sterile instruments and supplies needed for invasive trauma procedures. Trays include, but are not limited to, an open chest tray, a thoracentesis tray, and a pediatric and adult tracheostomy tray. Other trays include a laceration tray with a variety of different sutures and other sterile instruments that may be used for exposure/intervention. Most trauma teams will have a dedicated mayo stand (not shown) holding a sterile prepackaged trauma resuscitation tray that is ready in case an emergency patient requires its use. The tray contains local anesthetic, shaving equipment, gloves, betadine prep, and a variety of needles, syringes, and blades. These can be used to assist in a variety of procedures including resuscitative thoracotomy, chest tube placement, diagnostic peritoneal lavage, or repair of a bleeding laceration.

Figure 8 Intravascular lines and indwelling tubes cart. Located centrally between the several trauma resuscitation bays is the "lines and tubes" cart. This cart contains central lines, arterial line kits, intravenous fluids, a variety of chest tubes, Foley catheters, and pleurivac devices. In addition, the ancillary associated supplies are housed here, including sterile towels, gloves, and local anesthetic. Some splinting supplies are also housed here.

Initial communication begins with a call by the emergency medical service (EMS) system to the control desk (telecommunication control center) of the ED. Major trauma centers have devised different methods of announcing the arrival of traumatized victims to their team members. Whatever the terms of announcement, there must be a designated triage protocol so that all appropriate members of the trauma team arrive at the "trauma bay" to attend to the patient in a timely fashion.

Most modern trauma centers have worked out clear lines of communications between the hospital base station, the TRS and the EMS responders in the field. However, in disaster situations, where the number of patients overwhelms the care takers and outside agencies are called in to help, problems with communications between agencies remain an issue. Thus, local communities must have drills with their affiliate disaster partners to work out command and communication logistics ahead of time.

The U.S. military currently possesses the most advanced, sophisticated, and robust communication systems ever developed. These units can communicate via satellite at all levels of care within the patient management chain of command within their branch of the military. However, communication problems continue to exist among the

Table 2 Common Pharmacologic Agents Used in Trauma Resuscitation

Inotropic	Chronotropic	Vasopressors	Buffers	Sedative/hypnotic	Analgesic
Dobutamine	Atropine	Epinephrine	$NaHCO_3$	Propofol	Fentanyl
Dopamine	Glycopyrrolate	Norepinephrine	THAM®	Etomidate	Morphine
Epinephrine	Isoproterenol	Ephedrine	Carbicarb	Ketamine	
Calcium		Phenylephrine		Midazolam	
Amrinone		Vasopressin		Thiopental	
Milrinone					

various branches (i.e., air force, army, navy, national guard) from time to time. Unification of frequencies, equipment, terminologies, and protocols need to occur within these various institutions to improve patient management in large casualty situations (where interbranch cooperation is most likely to occur).

Preassigned Roles of Trauma Team Members

A critical component of TRS and trauma OR readiness is the continuous availability of a trained team whose goal is to provide the initial management of incoming trauma victims.

The hospital-based trauma team must be prepared to perform their responsibilities prior to arrival of the injured patients and must posses the skills, equipment, and support necessary to accomplish this objective. The core trauma typically consists of personnel as described in Table 3. Optimally, trauma team members know their own tasks as well as the skills and responsibilities of other squad members.

The core members of the trauma team assigned to receive and treat incoming patients consist of a team leader (referred to as "Dr. #1" in ATLS® parlance) along with one or two other doctors who assist "Dr. #1." The team leader is usually a trauma surgeon, but can be an anesthesiologist, ED physician, or other trauma-trained doctor. Generally, two nurses, a respiratory therapist, radiographer, and a medical record keeper assist the team leader.

The trauma team leader should be the most experienced team member present. However, in training hospitals this role is rotated among the trainees, although senior backup is always available. Before the patient arrives in the hospital, information is relayed from paramedics to the team leader, which helps to coordinate and establish priorities for investigation and management.

Apart from directing team members in their actions, the team leader is responsible for obtaining the medical history from the paramedics and the patient (when able), establishing treatment priorities, consulting with other specialists, speaking to relatives, as well as educating and debriefing team members. The team leader may later serve as the point person to give information to family and friends along with social worker, clergy, etc. Optimally, the leader's role should not be superseded by other late-arriving members or senior staff unless specific needs arise. Maintaining a single team leader for the duration of the resuscitation avoids confusion for the team members (see Volume 1, Chapter 6) and provides continuity of care (minimizing the chance of missing trends in care, losing important information, and inappropriately repeating studies to demonstrate previously recognized conditions).

Members of critical affiliated units that often receive trauma patients emergently [e.g., CT scanner radiologist and technologists, intensive care unit (ICU) staff, and the OR team] also need early notification of the trauma victim's imminent arrival. The key principle of good communication among the trauma team members is that the ED physician, trauma surgeon, anesthesiologist, ICU team, and nurse leaders remain in close contact, and all work to ensure that the other team members are apprised of relevant events as they evolve.

Noise Level Expectations

An appropriate professional working environment without excessive confusion and noise is part of team preparation and readiness for trauma. Noise in the TRS should be kept to a minimum so that the voice of the team leader can easily be heard by all, and assessments from other team members can be relayed back without competing for volume. **The ambient noise level is generally inversely related to the aggregate experience and coordinated activity of the trauma team.** The more experienced, the better coordinated; and, generally, the lower the level of ambient noise, the quieter the conduct of the resuscitation process. Sounds of pandemonium provoke anxiety in the patient and diminish the efficiency of the team members.

The record keeper should call out vital signs every 3 to 5 minutes (more frequently if deterioration in vital signs occurs) and everyone must be able hear these. The tone and volume should not change as the patient's condition becomes dire. Knowledge, training, and practice are important elements for efficient management of the injured patient by the trauma team (see Volume 1, Chapter 6). The key to maintaining cutting-edge team performance is the frequent practice that occurs in centers with large numbers of trauma patients. In other institutions, where trauma patients come less frequently, the trauma team members may need to practice resuscitation drills on an ongoing basis to stay sharp.

ATLS Training of Personnel

Trauma team preparation occurs at many levels, but perhaps of greatest importance is that each team member be fundamentally sound in terms of their knowledge and training in trauma and resuscitation. The ATLS course developed by the American College of Surgeons-Committee on Trauma (ACS-COT) is an important training tool for health care providers involved in the care of the trauma patient (6). It teaches a well-established lexicon of specialized terms and approaches trauma care in a systematic manner, with widely accepted diagnostic and treatment methodologies. Additional staff, outside those listed in Table 3, may need to be mobilized to provide ancillary services

Table 3 Responsibilities of Trauma Team Members

Team member	Preadmission	Primary survey	Secondary survey
Doctor 1[a] (head of bed)	Puts on lead apron Assigns roles Checks intubation equipment Gives preadmission plan Orders consults	Identifies self to paramedics Initiates eval./manages airway Immobilizes neck/C-spine Directs team members Decides # of IVs, orders type and amount of blood/fluids and medications Prioritizes x-rays and procedures	Orders lab work Orders consults Does head to toe/back exam Reads x-rays Decides disposition Talks with family
Doctor 2 (side opposite monitoring nurse)	Puts on lead apron Prepares a tray	Assists with airway Establishes additional IV access Manual control of bleeding from head/neck/torso Performs diagnostic procedures	Assists with clinical exam Assists with drawing blood Inserts monitoring lines
Doctor 3 (left leg)	Puts on lead apron Prepares trays	Undresses patient Assesses need for Foley Does rectal exam unless contraindicated Applies warm blankets	Examines lower extremities Immobilizes fractures Draws blood Does hem-occult test
Doctor 4 (right leg)	Puts on lead apron Readies supplies	Helps undress patient, inserts Foley Controls bleeding from lower extremities Assists with procedures	Does urine dip tests for blood Obtains urine for lab testing
Monitoring nurse	Writes MIVT info on board Sends out trauma page Puts on lead apron Flushes IV lines Readies videotape Pulls trauma "aka" packet	Assists with airway Assesses radial pulse and takes BP Gives vital signs Q 2–3 minutes Assesses IV patency and numbers IV bags Applies ID arm band	Gives meds and IVs Updates hemodynamic monitoring information (fluids, ABG, meds) Accompanies and monitors patients on transports
Circulating nurse	Puts on lead apron Flushes and cal's A-line Connects suction (Yankauer) Gets warm blankets	Ensures blood is processed Readies pleuravacs and autotransfusion Directs attainment of supplies Assists with procedures	Places ECG leads Readies transport equipment Calls other departments Takes temperature
Trauma tech	Readies (ice, tubes, syringes) for blood drawing Readies videotape Places patient info in log	Assists with obtaining equipment Collects valuables and clothes	Processes valuables and clothes Takes lab work to blood bank and labs as "trauma STAT" Pages consults, answers phone
MD consultant- (anesthesiologist)	Checks MIVT data re: anticipated airway needs Prepares airway equipment	Airway and ventilation management Resuscitation assistance/advice Sedation/analgesia advice	Airway and ventilation management Ongoing resuscitation, sedation, and analgesia assistance/advice
MD consultant-2 (neurosurgeon)	If anticipated CNS injury	Brain and spinal cord evaluation	Completes neurological evaluation
MD consultant-3 (surgical subspecialties)	Often required: orthopedics, ENT, max/face, plastics	Evaluates and treats area of specialty	Evaluates and treats area of specialty

[a]In most U.S. resuscitation suites, a surgeon is the team leader. However, in several U.S. hospitals the anesthesiologist performs this role (e.g., Children's Hospital Health Center, San Diego, California, U.S.A.). Furthermore, in Europe and Canada, anesthesiologists are usually the team leaders.

Abbreviations: "aka", also known as; ABG, arterial blood gas; BP, blood pressure; CNS, central nervous system; ECG, electrocardiogram; ENT, ears, nose, and throat; IV, intravenous; Meds, medications; MIVT, mechanism-injuries-vital signs-treatment.

when numerous severely injured patients arrive, and all should have current ATLS certification.

With practice, the trauma team functions as an efficient and rhythmic "orchestra" with different members performing individual roles in a "parallel" fashion.

In light of the current global threat of terrorism, all trauma teams should be equipped with at least some additional training to treat victims of chemical, biological, and nuclear disasters. The key considerations in training in this area should include magnitude and type of injury, the risk to providers of exposure and personal injury, integration between the hospital and the EMS in terms of the regional disaster plan, and increasing the specific knowledge at an individual practitioner level (7).

Laboratory Support

Trauma readiness requires that all supporting services are available 24 hours a day. Indeed, because many trauma emergencies occur during off hours, it is essential that the laboratory support services can function at a high level when daytime managers and extra workers are not present. The laboratory services that are most important during the initial, TRS period include the blood bank, the arterial blood gas (ABG) and clinical labs, radiology, and ultrasound services. Members from each of these services should be specifically assigned "on call" in-house to respond to incoming trauma.

Blood Bank

Close support from the blood bank is critical during every stage of trauma care, but especially at initial presentation and during the first hours of care. All tubes and required labeling must be available before the patient arrives. A clearly labeled and documented blood specimen from the patient should be sent to the blood bank as soon as possible. In case of massive hemorrhage, O-negative blood should be available immediately, and type-specific blood should be available within 10 to 15 minutes of the patient's arrival. Many centers will use O-positive blood in males if type-specific blood is not available. A fully crossmatched unit of packed red blood cells (PRBCs) typically requires around 45 minutes for completion. Fractionated blood products, such as fresh frozen plasma, platelets, and cryoprecipitate may also be required to treat coagulopathy in a trauma patient with multiple injuries. To minimize delays, communication with the blood bank must be optimized, and blood-sampling supplies must be ready-to-go prior to patient arrival.

Clinical Laboratory

The minimal laboratory tests required for the traumatized victim include (*i*) hematocrit; (*ii*) platelet count (obtained with complete blood count); (*iii*) coagulation profile [prothrombin time (PT), partial thromboplastin time (PTT), international normalized ratio (INR)]; (*iv*) ABG (which typically includes pH, PaO_2, $PaCO_2$, base excess, estimated HCO_3^-, electrolytes, ionized [Ca^{++}], and glucose); (*v*) electrolyte measurement (if not ordered in ABG) and BUN/Cr. Urinary pregnancy test should be obtained in young fertile females of childbearing age.

Supplemental laboratory tests, for example, repeat ABG, lactate levels, toxicology screen, troponin-I, and so on may be ordered based on medical history, clinical presentation, and resuscitation course. Using point-of-care testing can reduce turn around time in severely traumatized victims, where time is short. As with the blood-bank materials, blood sample tubes and labels must be available prior to the patient's arrival, and the patient's identifying information must be clearly and expeditiously stamped or printed on the STAT laboratory form to avoid needless delays. Some trauma centers will provide all incoming trauma patients with a preassigned trauma name and medical record number that is used for the initial resuscitation, helping to expedite all laboratory testing. Modern computer systems are capable of crosslinking the fictitious trauma name with the patient's old medical records, if known, to learn information about allergies, medications, and other important historical information.

Radiology

Immediate availability of the radiology technician is mandatory during the initial evaluation and management of the trauma victim. To facilitate this, the radiology department needs to be alerted to the patient's imminent arrival. The minimal initial radiological studies include a plain radiograph of chest and pelvis and lateral view of the cervical spine (Volume 1, Chapter 15). The radiology technologist should be proficient in obtaining optimal views of these and all other commonly injured areas to avoid wasting time re-taking radiographs. Most trauma centers have CT scanners located nearby or adjacent to the TRS. **In the future, CT scans will likely be physically located within the TRS (this is already true for some centers).** Interventional radiologists should be available within a reasonable time to help diagnose and control retroperitoneal hemorrhage and arterial (especially aortic) injuries that may require imaging beyond the helical CT scanner.

Ultrasonography

Ultrasonography is a valuable and sensitive tool for evaluating trauma patients. The use of this technique requires operator experience and training that are crucial for successful performance and interpretation of results. The ultrasound device and the technician should be present upon the patient's arrival. A portable focused abdominal sonography for trauma (FAST) exam can be used to quickly assess the abdomen for free intraperitoneal fluid (which is usually hemorrhage in a patient admitted with severe hemodynamic compromise or obvious shock) (4,5). The FAST exam of the abdomen, pelvis, and pericardial sac can be quickly accomplished to rule out hemorrhage. At the same time, several other critical intrathoracic considerations can be evaluated, including left ventricular contractility, left ventricular volume, the degree to which any pericardial fluid is causing tamponade physiology, and, in addition, whether a large hemothorax or pneumothorax can be seen. Surface ultrasonography is also useful in the assessment of fetal viability in a pregnant trauma patient. To evaluate the aorta, and to better interrogate the left and right heart chambers, a transesophageal echo (TEE) exam can be utilized in patients without esophageal injuries.

INTRAHOSPITAL TRANSPORT

Having a designated transport protocol for trauma patients constitutes another basic criterion for TRS readiness. In most institutions, the trauma resuscitation team transports the patient to the radiology suite or the SICU. Trauma surgeons, anesthesiologists, or ED physicians can head this initial resuscitation/transport team, depending upon the situation and institutional protocols. The fundamental considerations for transport are: (*i*) the patient is stable enough to endure the proposed transport; (*ii*) patients will be fully monitored (at least to the level provided in the TRS); (*iii*) resuscitation intensity will be continued (if needed); (*iv*) conditions will be set that will trigger immediate transport of the patient back to the TRS or on to the trauma OR.

Prior to intrahospital transport, patients should be evaluated fully, and during transport the monitoring levels should be at the same level or higher than used in the TRS. To be truly prepared, data management and coordination of care are other issues that must be solved before patients arrive. Additional transport considerations are reviewed in Volume 1, Chapter 7.

Pretransport Patient Evaluation

Timely evaluation and resuscitation are crucial to achieve a satisfactory outcome in trauma patients. The "golden hour" represents the window of opportunity for institution of life-saving measures and prevents death (8,9). A schema recommended by ATLS course includes primary survey (PS), resuscitation, secondary survey (SS), monitoring and evaluation, and transfer to definitive care. The PS is performed to identify immediately treatable life-threatening injuries (Volume 1, Chapter 8). The PS and resuscitation are performed simultaneously. The PS consists of A-Airway maintenance with cervical spine protection, B-Breathing and ventilation, C-Circulation with hemorrhage control, D-Disability, and E-Exposure and environmental control (6).

A key principle for reducing trauma morbidity and mortality is the establishment of a clear airway early on in patients who need it. Airway management is more complicated in acutely traumatized patients for several reasons. Unlike the elective surgical patients, the trauma patient can present to the ED or the trauma OR without prior evaluation of the airway. Patients may have sustained multiple injuries including trauma to the cervical spine (C-spine) or face. Patients may arrive at the hospital having just had large meals or a stomach full of alcohol. Definitive airway management is fully reviewed in Volume 1, Chapter 9.

Accordingly, the airway equipment must be prearranged in the TRS in an organized fashion. Respiratory insufficiency can result from direct causes: pulmonary contusion, penetrating injury, blast injury, or smoke inhalation. Lung injury can also result from indirect causes: sepsis, fat embolism, reaction to blood products, reaction to drugs, and tissue ischemia. Failure to maintain a patent airway for more than a few minutes can lead to brain injury or death and constitutes the single most common cause of anesthesia-related morbidity and mortality (13).

The goals of circulatory management during the PS are to evaluate the patient's hemodynamic status while controlling hemorrhage and restoring adequate systemic perfusion. Integral to this assessment is palpation of the pulse for rate, rhythm, and character. All elements of the circulatory status must be evaluated prior to transport. On the basis of the clinical assessment of hemodynamic status, patients can be classified into different stages of hemorrhagic shock (Volume 1, Chapter 8) (6, 30).

Arterial lactates and base excess can serve as surrogate markers of systemic tissue perfusion and both have been demonstrated to be predictive endpoints of resuscitation for trauma patients. Volume 1, Chapter 12 (initial circulation assessment and shock prevention) and Chapter 18 (ongoing resucitation endpoints and strategies) provide additional insights (31–33). Changes in preload are most marked in the hypovolemic state and are reflected in the systolic arterial pressure variation (SPV) (34).

A TEE probe can be placed following intubation to provide the best assessment of intravascular volume, myocardial contractility, and regional wall motion abnormalities associated with myocardial contusion or ischemia. The TEE can also be used as a diagnostic tool to evaluate pericardial tamponade, aortic injury, as well as large pulmonary embolus in an unstable patient (35). However, the TEE is not currently used to monitor hearts during transport. Other alternatives to thermodilution technique through a PA catheter include esophageal Doppler, Fick principle using carbon dioxide, and pulse-contour analysis (36).

Intraosseous infusion routes may be used to deliver fluid into venous drainage of the bone marrow if all peripheral veins are collapsed (37). Large-bore introducer sheaths (9 French) for PA catheters placed percutaneously in large central veins provide access for rapid administration of fluids and reduce the need for cut-downs (Volume 1, Chapter 10) (38).

Buffered salt solutions such as LR have been favored resuscitation fluids for years (39), though they are associated with upregulation of inflammation (Volume 1, Chapter 11). The excessive use of normal saline is associated with development of hyperchloremic metabolic acidosis (40,41). Newer formulas involving hypertonic saline (HS) and phosphodiesterase inhibitors (PTX) are being studied to decrease end-organ damage (Volume 1, Chapter 11); all of the appropriate fluid choices need to be immediately available in the TRS.

Transport Monitoring

Trauma patients frequently require transportation to a radiology suite for evaluation of injuries. Before leaving the trauma bay, the patient should be evaluated for adequacy, of airway, breathing and circulation, and response to initial interventions. Fractured extremities should be appropriately splinted prior to transport to minimize pain, blood loss, and the potential for further injury. Nonsplinted extremities can promote conversion of a closed fracture into an open one, or the progression of injury to arteries and nerves, or the development of a compartment syndrome (which in turn can cause neurovascular damage and/or rhabdomyolysis), see Volume 1, Chapter 29.

The patient with compensatory or occult shock may develop sudden decompensation without much warning. Unstable patients with clear mechanism of injury may be transported directly to the OR for "damage control," and then may either be brought to the radiology suite for further evaluation or intervention, or transported to the ICU. There is good evidence that the transfer of patients to and from the OR is associated with instability, especially the development of hypoxemia (42). Waddell found that 8.1% of intrahospital transports were associated with severe complications due to transport (42). Observation and monitoring during transportation should be done in accordance with local hospital policy; however, the standards should never be lower than those that apply in the ICU and the OR (43).

Data Management

The management of a trauma patient generates a vast amount of clinical data. The trauma flow sheet provides a comprehensive record of the patient's condition from initial presentation to final disposition, including during transport. It also provides information about the nature of interventions and diagnostic studies ordered in the trauma bay. Results of various laboratory tests, for example, hemoglobin, ABG, coagulation profile, and so on, should be clearly recorded in the trauma flow sheet. A number of injury severity scales, including ASA physical status, revised trauma score, Glasgow Coma Scale (GCS) score and injury severity score (ISS) form an integral part of the trauma resuscitation database (see Volume 1, Chapter 4). A well-designed trauma flow sheet provides an easily reviewed snapshot of the patient's course in the trauma bay. Appropriate and timely documentation of the results of studies, for example, C-spine radiographs, is extremely useful in the subsequent management of the trauma patient.

Coordination of Care

In the pretransport phase, the trauma team leader is responsible for planning the sequence of evaluation and treatment and for ensuring coordination among various groups, including the OR, the radiology department, and appropriate consultants. The families must be informed of pertinent findings and plan. In some situations, families are included during the resuscitation (46). Due to the dynamic nature of the pathophysiology of multiple injuries in a patient, sudden decompensation in the patient's condition may only manifest for the first time during transport to or in the radiology suite. The trauma nurse and respiratory therapist accompanying the patient must inform the team leader of any sudden change in the patient's condition. Immediate interventions, such as airway support and fluids may be life saving in this situation. Movement of the patient from the stretcher to the radiology table and back must be well coordinated to protect cervical spine, fractured extremity, and airway.

PHYSICAL PLAN OF TRAUMA OPERATING ROOM

The ACS *Optimal Resources for Care of the Injured Patient: 1999* states that a level-I and II trauma center should have an OR that is "adequately staffed and immediately available 24 hours a day." This dedicated trauma OR can be quickly utilized to treat multiple injuries in trauma patients with minimal prearrival notification. The economic and manpower feasibility of the dedicated trauma OR has been a topic of debate in the literature (47).

Ideally, the trauma OR should be located nearby or adjacent to the TRS to minimize transportation time for an unstable trauma patient. The schematic plan of a civilian level-I trauma OR, displayed in Figures 9 and 10, is a photograph of a dedicated trauma OR. An ergonomic arrangement of equipment is helpful for both patient and physician well being. Locating the lead aprons outside the trauma OR (Fig. 11) is helpful in facilitating the use of protective lead gowns prior to putting on their sterile OR attire.

Depending upon availability of personnel, each trauma OR will have a dedicated team to support the trauma surgeon, consisting of a trauma anesthesiologist, anesthesia resident, circulating and scrub nurse, and

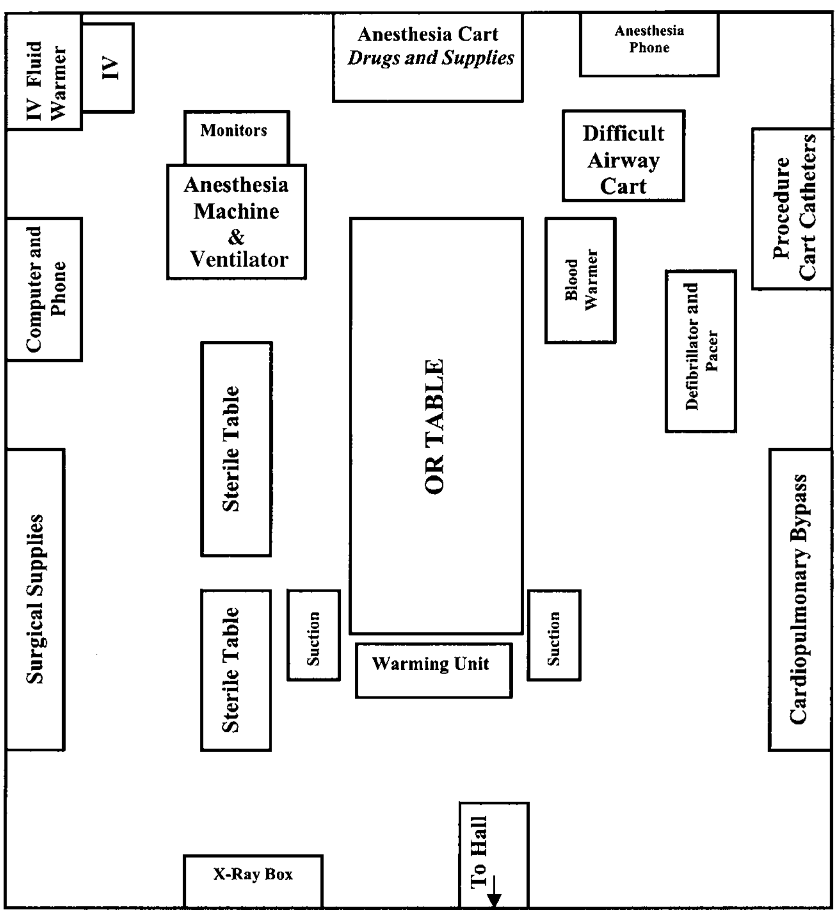

Figure 9 Schematic drawing of a dedicated trauma operating room (OR). This illustration displays the equipment and materials needed to care for trauma patients arranged around the centrally placed OR table. In addition to containing all of the supplies and equipment available in the trauma resuscitation suite, the trauma OR equipment needs include an anesthesia machine and other surgical supplies.

Figure 10 Trauma operating room (OR) at UCSD Medical Center. The trauma OR at UCSD Medical Center (a level-1 trauma center) is located on the same floor as the surgical intensive care unit and the trauma bay. The OR resuscitation room serves those patients who are deemed hemodynamically unstable during transport to the trauma center or have sustained certain injuries (e.g., gunshot wounds to the torso). This operating room is specially outfitted with built-in digital imaging machines and has OR surgical sets and anesthesia set up that are ready to be used as soon as the patient is brought in by paramedics.

anesthesia technician. Depending upon the nature of the injury, additional OR personnel can be mobilized, for example, perfusionist and cardiac surgeon. **A dedicated trauma OR provides a heightened level of preparedness in caring for injured patients, especially in penetrating torso trauma, where emergency surgery is most frequently required.**

In a military setting, the TRS and the trauma OR are combined when positioned in austere environments near the frontline. The physical layout depicted in Figure 3 shows the configuration recommended for NATO military units (described in greater detail later). The equipment needs will be similar between both civilian and military systems. However, the luxury of abundant supplies and resources found at civilian trauma centers is not practical in a military TRS/OR located near the battle zone.

Figure 11 Lead aprons and thyroid shields hanging on rack outside the trauma operating room (OR). This figure displays lead aprons and thyroid shields hanging on a rack on the right side of the door leading into Trauma OR #11 at the UCSD Medical Center. On the left side of the door is a cart containing the hats, booties, and gowns to be placed on top of the lead shields.

Equipment

Anesthesia Machine and Anesthesia Cart

The trauma anesthesiologist should prepare the airway and intubation "tools" ahead of time, as outlined in Volume 1, Chapter 9. The anesthesia cart will contain routine and emergency drugs and conventional airway equipment. The difficult airway equipment is stored in a separate difficult airway cart. Table 1 summarizes the airway equipment necessary to manage a difficult airway. The anesthesia machine in the trauma OR should be capable of applying positive-end expiratory pressure (PEEP) as well as providing pressure-limited mode of ventilation in a difficult-to-oxygenate patient with poor lung compliance. The function of these devices is confirmed by the trauma anesthesiologist ahead of time.

Fluid-Warming Devices

Blood and fluid warmers are essential components for any major volume resuscitation, as the rapid transfusion of cool fluids negatively affects resuscitation efforts. A rapid infusion device should be available to administer fluid and blood at the rate of 300–400 mL/min, at the same time effectively warming the fluid. Additional focused discussion on fluid requirements is provided in Volume 1, Chapter 11, and the initial resuscitation goals are reviewed in Volume 1, Chapter 12.

Procedure and Invasive Line Carts

Invasive procedures, such as resuscitative thoracotomy, surgical airways, and so on, are commonplace in trauma resuscitation. The instruments and equipment needed for these procedures should be readily available when needed. One of the best ways to ensure that the various items are available is to package the instruments and equipment in specialized trays and store them on a trauma procedure cart (Fig. 7).

In a similar fashion, invasive lines and tubes are placed during resuscitation for rapid replacement of volume and monitoring. The commonly utilized tubes and invasive lines are optimally prepackaged and stored on special "lines and tubes" carts (Fig. 8). The initial goal is to place two large-bore IVs as soon as the patient arrives. The placement of an intra-arterial catheter will allow the anesthesiologist to have real-time data on blood pressure. Sites commonly used include the radial and femoral arteries. Different sizes (12–20 gauges) of intravenous and arterial catheters should be readily be available on the "line and tubes" cart (Fig. 8).

Central venous catheters are placed for monitoring central venous pressures and evaluation of cardiac function. Common sites for entry into the central vasculature are: the internal jugular, subclavian, and femoral sites. Use of the Seldinger technique for rapid placement of an 8- or 9-French catheter introducer sheath does not require cut-down. A short 8.5 French catheter is currently available that allows flows of 300–400 mL/min of crystalloid or blood. Using vascular guide wires and vessel dilators, a smaller (18 or 14 gauge) venous cannula can be rapidly converted to such large volume systems. Line carts containing all of the necessary items required to perform these outlined procedures must be available.

Other Equipment

Other equipment in the trauma OR may include multiple infusion pumps for infusions of inotropes and vasopressors, autotransfusion devices to collect and process salvageable blood for auto-transfusion, devices for pacing and defibrillation, and/or an esophageal Doppler probe for hemodynamic evaluation, casting, immobilization, thoracostomy, and so on.

Pharmacologic Agents

Routine anesthetic practices and drugs can be easily modified for use in trauma patients. The anesthesia team is well aware of the potential side effects of some drugs that produce hypotension, cardiac arrhythmias, increased intracranial pressure, and rapid arterial oxyhemoglobin desaturation. These problems can be simplified and anticipated by careful evaluation of the patient's volume status and injuries to the specific organ systems. Almost all anesthetic induction drugs can be used in a properly volume-resuscitated patient. However, during the initial period following an injury, the patient may not be properly volume resuscitated.

Two commonly used induction drugs with the least significant vasodilator effects are etomidate and ketamine (48–50). These drugs, especially etomidate (with minimal myocardial depressant actions) should be available in all trauma induction areas. Other drugs, such as propofol and thiopental should be avoided, and when used must have their doses drastically reduced in hypovolemic patients. In these patients, the dosages that are necessary to produce unconsciousness are similarly decreased, due to reduced circulating volumes, relative hypoalbuminemia, and other considerations (51). Thus, close titration of drug administration during anesthesia is the keystone of therapy.

For maintenance of anesthesia, fentanyl and its analogs are the most commonly used agents. Standarized dosage regimens are inappropriate for the care of trauma victims. In these patients, the degree of hypovolemia, intensity of surgical stimulus, and the autonomic and somatic responses to surgical and traumatic injury and concomitantly used anesthetics vary widely, necessitating individualized dosages. Inhalation drugs (e.g., sevoflurane or isoflurane) play an important part in the management of anesthesia (52). However, nitrous oxide is typically avoided due to the possibility of exacerbating the expansion of extra-anatomic air in the thorax (pneumothorax), brain (pneumocephalus) or abdomen (abdominal compartment syndrome). A comprehensive review of the pharmacology of anesthetic drugs and the decision-making regarding their roles in various trauma conditions is provided in Volume 1, Chapter 19. These topics are briefly mentioned here only to ensure the presence of all useful anesthetic drugs and devices during the resuscitation and treatment phase.

A full set of vasoactive drugs including those used for ACLS should be available in the trauma OR. The vasoactive drugs can be easily stored in a multiple drawer wheeled cart, Syringe pumps and premixed solutions should also be stored in this cart so that infusions can be rapidly started. The ingredients for commonly used infusions should be assembled ahead of time (but not necessarily premixed). Commonly employed drugs that should be identified include: dopamine, norepinephrine, epinephrine, phenylephrine, and dobutamine. In addition, THAM® and vasopressin should be available to administer as infusions to correct severe metabolic acidosis and hypotension, respectively. Table 2 summarizes the drugs that should be preassembled and available in the trauma OR.

Laboratory and Blood Bank Support Personnel

Admission to the trauma OR should trigger release of additional personnel to specifically assist with laboratory, x-ray, and blood bank support. ABG analysis represents the most commonly utilized laboratory test in the trauma OR. In addition to the ABG measurement, the arterial gas "analysis" provides information regarding hematocrit, electrolytes (Na^+, K^+, and Ca^{++}), glucose, and lactate measurements for serial real-time intraoperative resuscitation of the trauma patient. Specific individuals must be available to carry stat samples to the ABG lab. Measurements of platelet count, prothombin and activated partial thromboplastin time, and fibrinogen are made on a periodic basis in a patient with multiple injuries requiring massive blood transfusions. Using point-of-care testing may reduce "turnaround time" in a severely traumatized patient, where time is of essence.

Close support from the blood bank is very important during every stage of care of a trauma patient. Type-specific or O-negative blood should be available from the blood bank at short notice for a massively hemorrhaging patient (as described earlier). Besides the need to physically carry blood products between the blood bank and the OR, there is often a need to help process the units at the blood bank.

All level-I trauma centers should institute "massive transfusion protocols." These protocols help expedite the availability of blood and blood products in such cases (see Volume 2, Chapter 59). Under these circumstances, help is often needed to check-in units of blood in the OR and to help administer those units. Similarly, fractionated blood products, such as fresh frozen plasma, platelets, and cryoprecipitate, will be needed to treat coagulopathy in a trauma patient with multiple injuries. Blood supplied by the blood bank must be clearly labeled, and there must be clear communication regarding ongoing needs and availability between all team members. All of these tasks should be predesignated to trained staff who will be available for all resuscitations.

Additional Anesthesia Monitoring and Support Personnel

It is essential for the anesthesiologist to have assistants immediately available in the trauma OR. Good help, sometime any help, may be difficult to find. Good help does not necessarily require physician-level training. An anesthesia technician who knows where things are kept and who can quickly set-up various pieces of equipment (e.g., Cell Saver, or rapid infusion devices or a TEG device) can be invaluable in the trauma OR during initial resuscitation and monitoring. Such resource people rarely get credit for their invaluable help. A pool of such individuals should receive on-going training. The nurses in the trauma OR should also be available to provide assistance (e.g., taking ABG samples to the lab and bringing blood products and uncommonly used drugs and checking in blood products). Close communication between different members of the trauma OR team—surgeon, anesthesiologist, nurse, and support personnel is extremely important.

Because many trauma patients arrive at the OR on short notice, a designated preprepared trauma OR allows the trauma anesthesiologist to rapidly assume care of the patient. For a hemodynamically unstable trauma patient coming to the OR, resuscitation should begin prior to transport and should be continued during transportation. The team leader communicates with the trauma anesthesiologist the mechanism of injury, results of the studies, and the proposed plan.

The trauma anesthesiologist should be well versed in dealing with complications, such as hemothorax, pneumothorax, pericardial tamponade, anesthetic overdose, hypoxia and hypoventilation, hypoglycemia, hypotension, and full arrest. Volume 1, Chapter 17 reviews the details of the preoperative evaluation and preparation and monitoring consideration. Intraoperatively, the trauma anesthesiologist plays a leading role in managing the resuscitation and communicates with the trauma surgeon when instability occurs, which would suggest the need for damage control, rather than definitive surgery.

MILITARY RESUSCITATION AND OPERATING ROOM CONSIDERATIONS

There are five "levels (previously known as Echelons) of care" recognized by NATO for the management of battle casualties (these are not to be confused with the ACS designation for trauma centers, which are inversely prioritized) (2). In the NATO system, the lowest level of support and treatment occurs at level I, and the highest is level V. An increase in the level of care corresponds with expanded availability of resources in the NATO system.

NATO level-I care is defined as that provided at the site of injury by the soldier himself or by buddies. Also included in this level are rudimentary medical treatment facilities (MTFs), known as Battalion Aid Stations (BAS), or Shock and Trauma Platoons (STP) where medics will be available to provide advanced first aid, the life saving therapy (e.g., chest tube insertion), and basic shock resuscitation. Surgery is not available at this initial level of MTF.

Limited inpatient beds and surgical services are available at a level-II MTF. These include the U.S. Army Forward Surgical Team (FST) (Figs. 12 and 13), the U.S. Air Force Mobile Field Surgical Team (MFST), U.S. Navy Casualty Receiving Treatment Ships (CRTS), and the U.S. Marine Corps Forward Resuscitative Surgical System (FRSS) (Figs. 14 and 15). Although hostilities in Iraq and Afghanistan have mainly changed from maneuver warfare to stabilization and containment, military medicine stations such as FST and FRSS level of MTFs continue to be deployed in numerous areas in both countries.

In austere environments, the military MTF deployed will vary in size and resources according to the nature of the mission, the shape of the battlefield and, to some extent, and branch of the military (e.g., army, navy, marines, etc.), and the nation providing the service. So despite the organization of levels of care, variability still exists between services.

Soldiers involved in deep infiltration across enemy lines will not have immediate access to a level-II MTF until a medical evacuation (MEDEVAC) team brings them out, usually by helicopter (see Volume 1, Chapter 7). Once medevac'd out, the solider would be transported to level-II MTF (e.g., army FST) or level-III MTF [e.g., army combat support

Figure 12 U.S. Army forward surgical team (FST) tent—exterior view. Highly mobile and rapidly erected, tents such as this are used by FSTs deployed by the U.S. Army. The FST tent shown here is manned by the U.S. Army FST deployed in Tarin Kowt, Southwestern Afghanistan in 2005. *Source*: Photo courtesy of José A. Acosta, M.D.

Figure 13 U.S. Army forward surgical team (FST) tent—interior view. This interior view of a U.S. Army FST tent shows that it would be used as both a resuscitation and operating suite. A very small area on the opposite side of the trauma tent is relegated for recovery (not pictured). The figure shows the frame for holding the litter; below is a plastic bag to collect blood and fluids. Hanging on the tent wall are various items utilized by anesthesiologists including endotracheal tubes, laryngoscopes, and so on. Only one surgical light is available in this FST tent. A "draw over" anesthesia machine is seen in the bottom right and behind the litter support structure. Numerous intravenous catheters are shown on the tent wall hanging on top right. Airway equipment is hanging on the tent wall center-right. On the floor is the anesthesia AMAL (trunk that contains all the equipment during transport). Plywood and plastic sheeting cover the floor to provide a sturdier surface and to protect the tent bottom. Note electrical extension cords are woven into upper corners of tent, and electricity comes from an outside generator. *Source*: Photo courtesy of José A. Acosta, M.D.

Figure 14 U.S. Marine Corps forward resuscitative surgical system (FRSS)—exterior view. In the foreground are two pallets containing all the equipment required for an FRSS. In the background is a fully erected FRSS tent in Ramadi, Iraq. *Source*: Photo courtesy of Joseph F. Rappold, CDR, U.S. Navy.

hospital (CSH)] depending upon triage criteria, MTF proximity to the casualty, among other considerations. The level-II MTF, such as the U.S. Army FST (Figs. 12 and 13) is and the Navy/Marine FRSS (Figs. 14 and 15) would typically be found near the front lines. These units must be mobile and tend to be relocated as the battle plan and lines of control evolve over time. The setup inside these level-II MTFs (Figs. 13 and 15) is generally arranged according to the U.S. Army (and NATO) authorized trauma bay configuration as shown earlier in Figure 3. The equipment needs that have been described previously must fit into the few storage and transport trunks that are provided, as shown in Figure 3.

The MTF with the most resources in a combat zone is found at the level-III care facilities (Figs. 16 and 17). These facilities (e.g., CSH) have expanded diagnostic, medical, and inpatient resources. A typical U.S. Army CSH has

Figure 15 U.S. Marine Corps forward resuscitative surgical system (FRSS)—internal view. Inside view of an FRSS in Ramadi, Iraq. An injured U.S. Marine has just been transported into the FRSS; he is intubated, mechanically ventilated, and is receiving intravenous fluids during the primary survey of his wounds. *Source*: Photo courtesy of Joseph F. Rappold, CDR, U.S. Navy.

Figure 16 Surgical intensive care unit (SICU) at the 325th Combat Support Hospital (CSH). Inside the SICU, numerous patients are cared for in an open ward setting. All major supportive devices were available (except dialysis) at the time of this photo, including mechanical ventilation, administration of parenteral and enteral nutrition (as shown), and use of computed tomography (though not available in nearby Kandahar). Most of the patients cared for in this SICU are Iraqis, as the vast majority of critically wounded American soldiers are flown to Landstuhl, Germany [to Landstuhl Regional Medical Center (LARMC) a level-IV facility] immediately following life-saving surgery, and then on to the United States. At the time of taking this photograph, a transition in the physical structure of the SICU had occurred from tents (Fig. 17) to the plywood B-huts shown in this image. *Source*: Photo is courtesy of José A. Acosta, M.D.

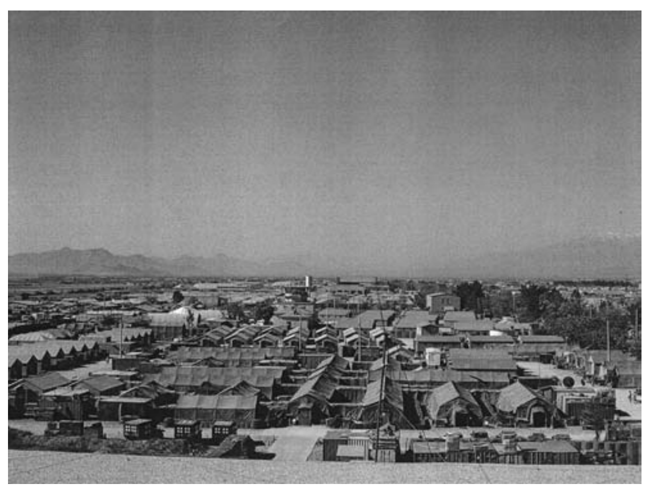

Figure 17 Aerial view of Afghanistan—the U.S. Army 325th Combat Support Hospital (CSH) and Bagram Airbase. This photo shows the interconnected reinforced tent-like structures in the foreground comprising the emergency department, operating room, and intensive care unit and main hospital wards of the 325th CSH at Bagram Airbase (just North of Kabul, Afghanistan). Clinics, administration, radiology, and full laboratory are also present. In the background, top left, is the Bagram Airfield with C-17s on the tarmac, and rows of Blackhawk helicopters configured for medical evacuation and military operations lining the airport perimeter on the left of the CSH complex. *Source*: Photo is courtesy of José A. Acosta, M.D.

numerous TRS/OR bays (Fig. 4) and a separate SICU, (Fig. 16) computed tomography and hospital beds for over 200 patients. After emergency surgery at a level-II MTF (e.g., FST tent as shown in Figs. 12–15) a patient may need to be nursed in the same site where it would serve as a temporary SICU until the patient is transported out to a level-III MTF directly to a level-IV facility, and as dictated by the type of injury and the combat conditions.

Outside of the combat zone, medical care is provided by field hospitals and general hospitals at a level-IV MTF. Level V care is found in the continental United States (CONUS) in both the Department of Defense (DoD) military and Department of Veteran Affairs (VA) hospitals.

The logistics of maintaining TRS and trauma OR readiness in wartime conditions vastly exceed those encountered in civilian practice. The additional logistical demands result from supply lines that are long, and because reserves of equipment and supplies must be minimized to balance the mission needs of trauma casualty readiness with the simultaneous combat requirements of mobility and rapid redeployment.

EYE TO THE FUTURE

Major trauma remains one of the most common causes of premature death in industrialized nations (53–55). The future of trauma management lies in improving each aspect of care including prehospital interventions, initial resuscitation, OR management and critical care. The advances in resuscitation, team management and the training using a systems approach, and telecommunications and research will have a major impact on outcomes after injuries.

Some of the issues related to prehospital interventions include the potential benefit of including a physician as part of the prehospital trauma care team and improving prehospital airway management, especially endotracheal intubation (56,57). Advances in the research in initial resuscitation will include novel approaches to treatment of shock including oxygen -carrying synthetic fluids to improve and sustain oxygen delivery, effective free radical scavengers to mitigate effects of hypoxic reperfusion injury, and use of modulated hypothermia to induce tolerance of ischemia and cellular hypoxia. The impact of these strategies on decreasing demand on limited blood bank resources and decreasing disabling complications of trauma remain to be seen. Advances in telecommunication technology and electronics will allow transmission of real-time images and improve communication and distant decision-making. Lastly, medico-legal and ethical implications of the presence of families during trauma resuscitation remain to be defined (46).

SUMMARY

Trauma remains one of the most common causes of premature death in developed and developing countries. The keys to positive outcome in trauma resuscitation are organization and preparedness, team approach, and clear communication and support from different members of the multidisciplinary trauma team. Early establishment of a clear airway and stabilization of circulation will reduce morbidity and mortality associated with trauma. Most trauma centers have designated Resuscitation Suites in the ED and OR. With practice and exposure, the trauma team functions as an efficient and rhythmic "orchestra," with different components performing individual roles in a "parallel" fashion. Challenges in the 21st century for trauma care include evolution of regional trauma systems, dealing with bioterrorism, reducing medical errors, and developing cutting-edge research to improve prehospital and inhospital outcome.

The advances in resuscitation, team training (emphasizing systems approach), and telecommunications will provide additional improvements in trauma outcomes. Military planners are constantly working to incorporate updated procedures and technology utilized in the civilian sector. Transport ability and reliance on electrical power are major constraints that must be overcome for each piece of technology and equipment used in the battle zone. Both civilian and military TRS and trauma ORs have the same setup requirements to be prepared to handle incoming trauma victims. However, the resources are generally more limited in military settings during wartime. Preparation of equipment and facilities prior to patient arrival is the hallmark of top level care regardless of its setting.

KEY POINTS

- Organization and preparedness, along with clear communication and expert support from all members of the multidisciplinary trauma team, constitute the keys to success in trauma resuscitation.
- The configuration of the NATO trauma bay is arranged according to a predefined plan so that physicians, nurses, and medic assistants from different countries will know where items are expected to be located.
- Whenever multiple trauma bays are located within the same TRS, each one should be set-up in a similar (optimally identical) fashion.
- An essential component of trauma OR and TRS preparedness is the establishment of a robust communication system with clear lines of correspondence throughout all stages of management.
- A critical component of TRS and trauma OR readiness is the continuous availability of a trained team whose goal is to provide the initial management of incoming trauma victims.
- The ambient noise level is generally inversely related to the aggregate experience and coordinated activity of the trauma team.
- With practice, the trauma team functions as an efficient and rhythmic "orchestra" with different members performing individual roles in a "parallel" fashion.
- In the future, CT scans will likely be physically located within the TRS (this is already true for some centers).
- A key principle for reducing trauma morbidity and mortality is the establishment of a clear airway early on in patients who need it.
- A dedicated trauma OR provides a heightened level of preparedness in caring for injured patients, especially in penetrating torso trauma, where emergency surgery is most frequently required.
- All level-I trauma centers should institute "massive transfusion protocols."
- The advances in resuscitation, team training (emphasizing systems approach), and telecommunications will provide additional improvements in trauma outcomes.

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6

Trauma Team Performance

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INTRODUCTION

The role of effective teamwork in accomplishing complex tasks is accepted in many domains. Similarly, there is good evidence that the outcome in trauma care depends on effective trauma team performance. Teamwork during trauma care can be deficient in a number of ways (Table 1), and multiple deficiencies may interact to impair team success and patient outcomes. This chapter focuses on understanding, assessing, and improving trauma team performance. Resuscitation of trauma patients is a specialized domain in which critically ill patients are treated in a dedicated facility. The need to train and evaluate the performance of trauma teams has emerged as an important topic over the past decade (1,2). Institutions must establish and continuously validate their team-based trauma resuscitation procedures to assure high quality care. This iterative evaluation must include the review of secondary management, careful delineation of team structure, comprehensive team training, effective support structures, and continuous quality improvement. This chapter reviews the state-of-the-art methodology useful for the trauma team's training, evaluation, and improvement. Emphasis is placed upon essential features and newer techniques, including computer simulation and video-assisted analysis and debriefing.

Team training has a proven history in aviation and military organizations. Recently, these experiences and techniques have been utilized in medicine, including trauma resuscitation and critical care management. Studies of aviation teams revealed failures of coordination, communication, workload management, loss of group situational awareness, and inefficient resource utilization (3–6). Thorough investigation of adverse events occuring during trauma resuscitation revealed similarities to failures discovered in aviation-related mishaps, both tending to be multifactorial and complex (7–11).

Much of health care is performed by interdisciplinary teams: individuals with diverse specialized skills focused upon a common task in a defined period of time and space, who must respond flexibly to contingencies and share responsibility for outcomes. This is particularly true of trauma care. Traditional specialty-centric clinical education programs are deficient in team training, because most assume that individuals acquire adequate competencies in teamwork passively without any formal training. Performance incentives in health care are targeted at individuals and not at teams, as are job and other selection and assessment processes (12). With a few exceptions, risk management and liability data, morbidity and mortality conferences, and even quality improvement projects have not systematically addressed systems factors or teamwork issues. Substantial evidence suggests that teams routinely outperform individuals and are required to succeed in today's complex work arenas where information and resources are widely distributed, technology is becoming more complicated, and workload is increasing (13,14). Nevertheless, our understanding of how medical teams coordinate in real-life situations, especially during time-constrained and crisis situations, remains incomplete.

TEAM DEFINITION AND RELEVANCE IN TRAUMA

One must distinguish between a group of individuals sharing a common task (e.g., a jury) and a team (e.g., a marching band, football team). A team is "a small number of people with complementary skills who are committed to a common purpose, performance goals, and approach for which they hold themselves mutually accountable" (14). Weick and Roberts (15) defined medical teams as "a loosely coupled system of mutually interacting interdependent members and technology with a shared goal of patient care." Katzenbach and Smith (14) argued that any performance situation that warrants a team effort must meet three criteria: (*i*) Collective work products must be delivered in real-time by two or more people; (*ii*) Leadership roles must shift among the members; and (*iii*) Both mutual and individual accountability is necessary. They go on to assert that teams must have a specific team purpose (distinct from that of its individual members), that they have shared performance goals and a commonly agreed upon working approach, and that a team's collective work products are generally used to evaluate the team's performance (14). Others have suggested that smaller teams (5–10 members) are generally more effective than larger ones, partially due to familiarity, cross-checking, and interdependence. According to Weinger, **Effective teams possess five characteristics of success (the five Cs): commitment, common goals, competence, consistency (of performance), and communication (16).**

Team Competence

Team competence is measured across multiple dimensions that include technical, decision, and interpersonal skills.

Table 1 Problems and Pitfalls in Trauma Teamwork

Difficulties coordinating conflicting actions
Poor communication among team members
Failure of members to function as part of a team
Reluctance to question the leader or more senior team members
Failure to prioritize task demands
Conflicting occupational cultures
Failure to establish and maintain clear roles and goals
Absence of experienced team members
Inadequate number of dedicated trauma team members
Failure to establish and maintain consistent supportive organizational infrastructure
Leaders without the "right stuff"

Source: From Ref. 19.

The diversity of team members with complementary skills is a hallmark of many effective teams, particularly when the team is required to adapt to complex and changing circumstances. Acute care medical teams, including trauma teams, typically excel at the first two Cs (commitment and common goal) and explicitly strive for competence, but may be much less successful in their consistency of performance (i.e., ability to sustain best practice at all times). The effectiveness of communication between team members requires persistent efforts from all (17–19). The best trauma teams maintain an intuitive understanding of the evolving processes of events (see discussion in the latter part of this chapter of team situation awareness); they appreciate and expect the unknown; and there is a high level of honesty, respect, and trust between team members (20).

Team Member Conflict Resolution

Conflicts among members are inevitable in every team, and many experts believe that conflict, and its successful resolution, is essential to attaining maximal team performance (13,14). The natural tendency, especially among health-care professionals, is to avoid or gloss-over conflicts. However, doing so can sew the seeds of impaired team performance when the next challenge arises. There are four primary conflicts inherent in teamwork (21): First, tensions occur between individuals and the team as a whole in terms of goals, agenda, and the need to establish an identity (22). Second, to attain optimal team performance, one needs to foster both support and confrontation among team members. If team members are unwilling or unable to challenge each other's decisions respectfully, then there is a real risk of poor team outcomes. A team devoid of conflict leads to "group think" (23) and the acceptance of suboptimal team decisions. Third, daily team activities must balance moment-to-moment performance against the need to continually enhance team learning and individual member development. Finally, the team leader must find a balance between managerial authority, on the one hand, and individual team member autonomy and independence, on the other.

ORGANIZATION OF THE MODERN TRAUMA TEAM

The trauma resuscitation and management system is one of the most demanding in healthcare, incorporating very ill patients, a diverse range of care providers, management decisions based upon clinical evaluation, and complex imaging modalities, all occurring under severe time constraints. The trauma team, which assembles rapidly at unpredictable times, must be prepared for sudden, unique, and chaotic situations involving one or more patients presenting with initially unknown injuries.

The successful management of trauma requires effectively coordinated prehospital care and information management, followed by transfer to a well-organized and well-prepared trauma resuscitation suite (TRS) or operating room (OR), (see Volume 1, Chapter 5). During the trauma resuscitation, the team typically adheres to hospital protocols based on the Advanced Trauma Life Support® (ATLS®) management protocols. In most modern trauma teams, multiple team members have dedicated roles and simultaneously perform separate patient-care tasks (24,25). While more efficient, and leading to more rapid resuscitation, this kind of horizontal structure requires much better team coordination, leadership, and organization (24,26,27). Studies in advanced trauma units have highlighted the difficulties of attaining effective teamwork, noting team breakdowns under dynamic conditions (28).

Trauma teams typically consist of 5 to 10 individuals from several clinical disciplines. Traumatologists, usually general surgeons, anesthesiologists, or emergency medicine physicians serve as team leaders, first responders, or other team members (26). Airway management is commonly performed by anesthesiologists or emergency physicians, with support from a respiratory therapist. Specialized trauma nurses as well as pharmacists, radiological technicians, and other ancillary personnel (e.g., laboratory technician, orderlies, etc.) may round out the team together with residents and medical students. Predefined roles (specific task allocation) and even the physical location (trauma resuscitation room or suite) around the trauma patient are commonly proscribed (Volume 1, Chapter 5).

More generally, medical teams, consisting of a multidisciplinary group of members, might form for a single clinical event (e.g., a specific surgical procedure) or be together for a short defined period (typically a month or so). Not infrequently, some team members are consistent and well defined (e.g., the emergency department team) while others join on an ad hoc basis (e.g., respiratory therapists, pharmacists, anesthesiologists). Thus, a specific group of individuals may only infrequently have the opportunity to work together. This can be true of trauma teams as well, especially given the high workload of trauma care. Further, trauma care is often provided in academic medical centers where the trainees, who comprise much of the trauma team, rotate on and off the service on a regular basis. Research in aviation shows that such "rostered teams" are less effective than more stable "fixed" teams (29). In addition, Simon et al. (30) have shown that rostered teams are less likely than fixed teams to call each other on safety infractions.

The Trauma Team Leader

The resuscitation team leader's functions may include the performance of specific tasks, such as conducting the primary and secondary surveys (Table 2). However, given sufficient personnel, the team leader must assume, as quickly as possible, a supervisory role, prioritizing and delegating tasks and reviewing and overseeing the team's (and patient's) progress throughout the resuscitation (26,31). Studies suggest that trauma teams are less effective when the team leader spends significant time performing procedures rather than delegating them to other team members (27).

Table 2 The Trauma Team Leader's Responsibilities

Know the job (e.g., know ATLS® guidelines cold)
Communicate clearly and effectively
Enhance the team's communication
Foster teamwork attitudes through tangible behaviors
Keep the goals and approach relevant and focused
Enhance the team's knowledge and shared expectations
Build commitment, confidence, and trust
Remain positive and supportive, especially under adverse conditions
Acknowledge and manage your own limitations and those of the team
Strengthen the skills of each team member and of the team as a whole across all performance dimensions: technical, functional, problem solving, decision making, interpersonal, and teamwork
Manage relationships with outsiders and remove obstacles
Create opportunities for others to grow into leadership roles
Lead by example
Reward team performance and discourage individualism that detracts from team performance
Provide constructive feedback and opportunities for practice

Abbreviation: ATLS®, Advanced Trauma Life Support®.
Source: From Ref. 27.

However, the team leader should have recognized expertise in treating trauma patients, and be willing and able to intercede when other team members are not performing up to acceptable standards (also see a list of duties provided in Volume 1, Chapter 5).

The team leader is also responsible for formulating (or at least approving) the definitive treatment plan. Thus, the team leader must quickly assimilate a large amount of disparate information from other team members with personal observations. This leads to an overall assessment, which includes decisions about therapeutic and diagnostic interventions. The leader also communicates with team members, coordinates consultations, makes triage decisions, and ensures that all team members are aware of the evolving situation.

Although skill and experience are valuable for every member of the team, it is particularly critical for the trauma team leader. **Studies show that the presence of a single identified trauma resuscitation team leader leads to a better secondary survey, ATLS guideline adherence, and team coordination (32).** Better team coordination is achieved when the definitive treatment plan is facilitated by a team leader who is an experienced traumatologist. The personality of the team leader has a large impact on team performance. Work by Chidester, et al. (33) led to a broad classification of three personality types of team leaders: "right stuff," "wrong stuff," and "no stuff" (Table 3). Teams led by individuals with the "right stuff" performed better than those led by leaders with "no" or "wrong stuff." In addition, Bowles et al. showed that air crews led by "right stuff" captains performed well with less stress than those led by other personality types (3). Successful team leaders know and emphasize that the goal is team performance rather than individual achievement. Team-oriented behaviors, which do not come naturally in a culture that rewards individualism above teamwork, can be learned and practiced.

Other Members of the Trauma Team

Successful resuscitation and recovery from trauma requires an immediately available multidisciplinary team capable of

Table 3 Team Leader Personality Types

Right stuff	Wrong stuff	No stuff
Active	Authoritarian	Unassertive
Self-confident	Arrogant	Low self-confidence
Interpersonal warmth/empathy	Limited warmth/empathy	Moderate warmth/empathy
Competitive	Impatience and irritability	Noncompetitive
Prefers challenging tasks	Prefers challenging tasks	Low desire for challenge
Strives for excellence	Strives for excellence	Doesn't strive for excellence

Source: From Ref. 3.

evaluating and managing life-threatening injuries. The trauma team leader works closely with these other trained experts in trauma care. All essential team members (e.g., trauma surgery, anesthesiology, surgical critical care, neurosurgery, orthopedic surgery, interventional radiology, and blood banking) must be available 24 hours a day, seven days a week, to provide optimum care and meet the requirements for a level-1 trauma center.

The initial focus of the trauma resuscitation is airway, breathing, circulation, and control of hemorrhage (discussed in Volume 1, Chapter 8). Although the team leader must be cognizant of each of these care goals, the definitive management of each is best delegated to other members. For example, the anesthesiologist is best trained and capable of managing the airway and assessing breathing, and one of the surgical assistants should be employed to control hemorrhage, while other team members place intravenous lines, chest tubes, etc. Although each of the assistants could operate autonomously, the resuscitation will be most effective if each team member's activities are overseen by the team leader.

Trained professionals, with extensive experience in trauma management, will provide better care than novice clinicians. In most busy trauma centers, established professionals both model and teach students and trainees the correct approach. They must balance allowing students and trainees to gain practical experience with close supervision to assure proper patient care. Even trained experts will confront difficult circumstances at times [difficult airway, poor intravenous (IV) access, uncooperative patients, etc.]. However, proper training, rest, and environmental support will help rescuers overcome these obstacles.

HUMAN FACTORS IN THE TRAUMA ENVIRONMENT

Human factors (also called ergonomics) is the study of human interactions with tools, devices, and systems with the goal of enhancing safety, efficiency, and user satisfaction. Human factors emerged as a recognized discipline during World War II. Its use improved military system performance by addressing problems in signal detection, workspace constraints, optimal task training, cockpit design, and teamwork (34). Nearly half a century of research and hands-on experience have produced a substantial body of scientific knowledge about how people interact with each other and with technology. The knowledge and techniques of human factors have been productively applied to enhance performance in a wide range of domains, from fighter planes to the TRS and the trauma OR.

Human factors research on team decision-making in complex task environments is of relevance to trauma team performance (4,35–38). One must carefully consider the impact of the many "performance shaping factors" that can degrade human capabilities (Table 4). One must also understand how best to optimize trauma care (39–42). The environment in the field, in the air, and in the hospital greatly affects and shapes the outcomes of trauma teams. Factors that influence the team's effectiveness include the performance of individual team members, the equipment they use, the TRS and trauma OR environment (e.g., established care process and procedures), and the underlying organizational and cultural factors. For example, distracters such as information overload, noise, spectators, and physical obstacles can be a danger to both the patient and health care professionals. Although there is insufficient space in this chapter to discuss all of the performance-shaping factors of relevance to the trauma team, a few of the more pertinent factors are described in more detail in the following sections.

Table 4 Examples of Performance-Shaping Factors Affecting Trauma Care

Performance shaping factor	Example
Individual factors	Clinical knowledge, skills, and abilities Cognitive biases Risk preference State of health Fatigue (including sleep deprivation, circadian)
Task factors	Task distribution Task demands Workload Job burnout Shiftwork
Team/communication	Teamwork/team dynamics Interpersonal communication (clinician–clinician and clinician–patient) Interpersonal influence Groupthink
Environment of care	Noise Lighting Temperature and humidity Motion and vibration Physical constraints (e.g., crowding) Distractions
Equipment/tools	Device usability Alarms and warnings Automation Maintenance and obsolescence Protective gear
Organizational/cultural	Production pressure Culture of safety (vs. efficiency) Policies Procedures Documentation requirements Staffing Cross coverage Hierarchical structure Reimbursement policies Training programs

Source: From Refs. 39, 40, 41, 42.

Sleep Deprivation and Fatigue

Extensive literature exists on the adverse effects of sleep deprivation and fatigue on an individual clinician's performance (40,43–46). These studies and other events have led to work hour limits of clinicians in training. Most studies of recurrent partial sleep deprivation have suggested that sleeping only five to six hours a night can lead to performance impairment (47). Sleep loss most acutely degrades performance on tasks requiring vigilance, cognitive skills, verbal processing, and complex problem solving (43,46). Performance decrements begin with a lack of appreciation of the skills being degraded and accumulate with continued partial sleep deprivation. This may be seen in trauma physicians working regularly on recurring call or night shifts. In the early morning hours, after nearly 24 hours without sleep (e.g., at the end of difficult on-call shift), psychomotor performance can be impaired "to an extent equivalent to or greater than is currently acceptable for alcohol intoxication" (49). Two recent laboratory simulation studies, involving sleep-deprived surgeons, demonstrated significant impairment in surgical skill (both speed and accuracy) in a virtual reality simulation of laparoscopic surgery (48,50). Although the impact of fatigue on "team performance" has thus far been sparsely studied, the results may be expected to be similar with trade-offs between the benefits of team compensation and redundancy on the one hand and impaired team communication on the other.

The effect of an individual team member's sleep deprivation (or other performance detractors such as working when ill) on the overall trauma team's clinical performance depends on several factors, including time of day (circadian effects), clinical experience, task demands, clinical workload, and other team members' level of functioning. The current body of evidence suggests that a sleep-deprived or fatigued trauma team will make more errors, be less likely to recover from these errors, and provide lower quality care than a well-rested team. Organizational leaders must, therefore, design work schedules to provide adequate rest periods for the team members.

Stress and Job Performance

Sources of stress that affect job performance include social and physical stressors; the tasks involved, such as mental workload and pacing of activity; as well as individual characteristics such as health, fitness, and personality (51). Personal factors, such as financial concerns or a recent dispute with a spouse, can adversely impact job performance and even increase the likelihood of accidents (52). Training and experience reduce the subjective impact of the stress and workload associated with emergency situations, thus, the value of formal emergency drills, whether in aviation or medicine (53).

In an airline transport study, air crews that had the highest performance experienced less stress than did lower performing teams (3). Thus, undue stress can impair performance and impaired performance can cause undue stress. The take-home message for the trauma team is to: (*i*) identify explicitly and manage the sources of stress for the team and its members; (*ii*) actively train to reduce stress and enhance performance, especially during high tempo, high workload periods (e.g., multiple simultaneous trauma resuscitations), and (*iii*) include risk reduction and fatigue countermeasures as part of every clinical debriefing.

Environmental Factors (e.g., Noise, Clutter, Disorganization)

The environment of care contains a number of factors that influence team performance including noise, lighting, temperature, the need for protective gear, clutter, disorganization, and impaired physical access to the patient, or essential tools or equipment, or both. In the interest of brevity, only the effects of noise are discussed in detail. The noise level in acute care environments can be quite high. For example, continuous background noise in the modern OR typically ranges from 75 to 90 dB, and can increase to almost 120 dB (e.g., during high-speed gas-turbine drill use) (39). Although apparently never measured, it is reasonable to assume that sound pressures in the typical trauma unit are similar or louder than those found in surgical suites. In the trauma unit, noise can be generated by multiple conversations, mechanical ventilation, suction, overhead pages, use of medical equipment, and alarms. **High noise levels create a positive feedback situation, where noisy rooms require louder voices and higher volume alarms leading to increased noise levels, missed clinical events, and greater team dysfunction.**

High noise levels interfere with effective verbal communication. This may be important during trauma resuscitations when it is critical for team members to hear clearly other members of the team. High noise levels in trauma units can also detrimentally affect short-term memory tasks, mask task-related cues, impair auditory vigilance (for instance, the ability to detect and identify alarms), and cause distractions during critical periods (39,40). Exposure to loud noise activates the sympathetic nervous system affecting mood and performance. The resulting stress response has been suggested to interact with other performance-shaping factors resulting in impaired decision-making during critical clinical incidents (40).

Interpersonal Communication

Both verbal and nonverbal communication are critical to the success of team performance (6). Failures of team communication lead to medical errors and adverse outcomes (18). In highly complex nonmedical domains that involve teamwork (e.g., aviation crews, submarines), the team has often been together a long time and is well practiced. Effective team communications involve unspoken expectations, body language, traditions, and general assumptions about task distribution, command hierarchies, and individual emotional and behavioral components. A study found failures of adequate communication between clinical care providers in the ICU contributed to medical errors (18). In this study, more than one-third of all patient-care errors reported were associated with failures of verbal communication. These communication failures occurred not only between nurses and physicians, but also between nurses. Similarly, analysis of videotaped trauma team performance showed that highly skilled teams communicated in a variety of ways, many of which were nonverbal and implicit (54). Team coordination breakdowns were manifested by conflicting plans, inadequate support in crisis situations, failure to verbalize problems, and poor delegation of tasks.

Because trauma teams are composed of clinicians from many different disciplines (i.e., physicians, nurses, pharmacists, etc.) with their own norms, expectations, attitudes, and cultures, effective team communication must overcome these barriers. Dutton et al. (55) recently showed that regularly scheduled multidisciplinary "discharge rounds" in a trauma hospital not only facilitated communication but dramatically improved patient flow with a 36% increase in patient volume and a 15% decrease in length of stay.

Team performance can be adversely affected by dysfunctional interpersonal interactions among team members. Such "miscommunication" often stems from a lack of shared expectations, beliefs, or training (56). Thus, trauma teams can enhance their performance by spending more time together, not just during formal training, but also through joint conferences and social events. **Trauma team members must make special efforts to communicate clearly and unambiguously, especially when members of the team are new or less experienced.** Effective team communication is more difficult when some or all of the team are subjected to other stressors, such as sleep deprivation and fatigue.

KEYS TO EXPERT DECISION MAKING FOR TRAUMA

Traditional theories of decision making assume that individuals and teams use a deliberative approach in which they assess the relative risks and benefits of multiple options. However, in the 1980s, researchers began to study the way experienced people actually make complex decisions in their natural environments, or in simulations that preserve key aspects of their environments (naturalistic decision theory) (57). These studies demonstrated that, in contrast to "normative decision theory," experts make real-world decisions through a serial evaluation and application ("trying on") of options that seem appropriate to the apparent situation. Naturalistic decision theory argues that, especially under time pressure in complex task domains (e.g., trauma units), experts recognize situations, or their integral components, as typical or familiar and then respond to each specific situation with appropriate preprogrammed patterned responses. Choosing the first acceptable response that comes to them is called "recognition-primed decision making" (57,58). Thus, competent decision-makers in complex domains are very concerned about quickly assessing and maintaining awareness of the current clinical situation.

Correct Decision Making with Incomplete/Conflicting Data

Expertise is more than simply having extensive factual knowledge—it also includes complementary skills and attitudes. Experts have specific psychological traits (e.g., self-confidence, excellent communication skills, adaptability, risk tolerance) and cognitive skills (e.g., highly developed attention, sense of what is relevant, ability to identify exceptions to the rules, flexibility to changing situations, effective performance under stress, ability to make decisions, and initiate actions based on incomplete data). Clinical experts use highly refined decision strategies such as dynamic feedback, decomposing and analyzing complex problems, and prethinking solutions to tough situations (59).

A key attribute of expertise in trauma care is the ability to anticipate or to predict what might happen to a patient with a particular constellation of injuries given the resources available. Mental simulation, whereby individuals or teams envision (simulate) a possible future clinical event or clinical action before it happens, is essential to gain the expertise to make diagnoses and to perform at a high level during an evolving or future real event. When expert clinicians simulate situations and actions mentally before they undertake them in real life, they save time and improve performance in crucial situations (see simulation section below).

Situation Awareness

One of the most important decision skills in trauma care, where data overload is the rule and the patient's status changes continually, is the ability to recognize clinical cues quickly, detect patterns, and set aside distracting or unimportant data. Situation awareness (or situation assessment) is a comprehensive and coherent representation of the (patient's) current state that is continuously updated, based on repetitive assessment (60). Situation awareness appears to be an essential prerequisite for safe operation of any complex dynamic system. In the case of trauma care, adequate "mental models" of the trauma patient and the associated trauma unit facilities, equipment, and personnel are essential for effective situational awareness. Situation awareness can be divided into three levels (Fig. 1) (60,61) and successful team awareness allows all members to converge on a shared mental model of the situation and course of action (62). **Effective teams adapt to changes in task requirements, anticipate each other's actions and needs, monitor the team's ongoing performance, and offer constructive feedback to other team members (62).** When team members share a common mental model of the team's on-going activities, each will "instinctively" know what each of their team-mates will do next (and why), and they often communicate their intentions and needs nonverbally ("implicit communication").

TEAM TRAINING TECHNIQUES

Team training should be designed based on desired team competencies (behaviors, attitudes, skills, and knowledge) and specific tasks to be trained for. Each training exercise should have explicit learning objectives. Team training exercises are best oriented around realistic scenarios that will address the learning objectives, facilitate team decision-making, and provide specific task training. This section reviews some common team-training approaches, spanning the spectrum from traditional exercises to newer "high tech" techniques, only recently made possible by high-speed computer simulation programs and the evolution of video analysis.

Traditional Team Training Exercises

Application of nonmedical studies on health care team-training methods remains largely invalidated. However, several findings may be instructive to those striving to provide trauma team training. First, training sessions should link the requirements of the task and the environment to the competencies required of team members (63). Second, training that fosters communication of the team leader's evolving picture of the situation to the team can enhance the team's behaviors (64). Thus, team practice should include periodic situation updates by the team

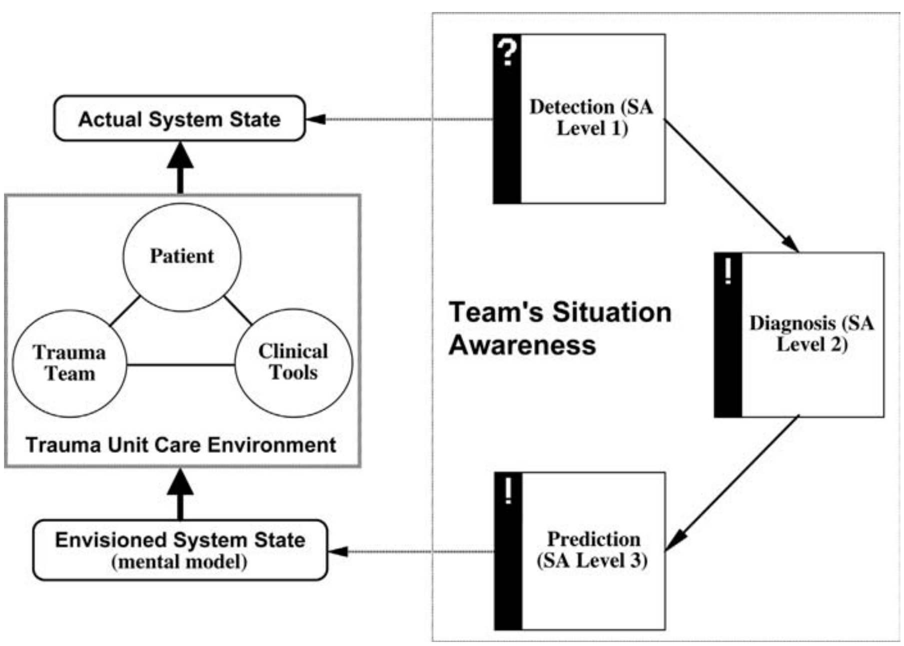

Figure 1 The role of situation awareness in trauma care. Situation awareness consists of three levels: Level 1—detection (perception) of changes in the patient's state, other team members' performance, or the status of equipment or the surrounding environment. Level 2—a diagnosis of the current state of the "system," which includes the patient, the team, and the care environment. This leads to a revised "mental model" used to evaluate the meaning of future changes. Level 3—prediction of future patient/system state leading to the choice of appropriate interventions to optimize patient outcome. *Abbreviation*: SA, situation awareness.

leader. Third, task stressors influence team communication, coordination, and performance strategies. Therefore, training should incorporate methods to build team mental models and provide relevant and meaningful information about the impact of other team members, tasks, equipment, care environment, and the evolving situation. Fourth, teams should practice in simulations or with role-playing in a relevant context. Fifth, training effectiveness should be assessed under both routine and realistic stressful conditions. Finally, training exercises must incorporate ongoing feedback about team performance.

For trauma teams to improve, they must share common performance goals and an understanding of the work to be done together. Teams with shared mental models are more likely to have accurate expectations of the team's needs than those without shared models, thereby allowing them to adjust behavior during stressful situations and to anticipate changing conditions. Three team performance-enhancement strategies that can foster common goals and shared mental models among team members are cross training, team model training, and crew resource management training.

Cross Training

It is challenging to maintain high levels of performance with the frequent turnover of personnel, as is common in academic medical centers. Cross training of trauma team staff in each other's roles provides both flexibility and enhanced team performance. An important benefit of cross training is improved team communication by facilitating development of shared expectations of each other's roles, decision processes, and actions of the team members. Common training regimens (e.g., ATLS) and practice in the tasks performed by other team members enhance knowledge of the team's needs and also promote anticipation and coordination (65). Volpe et al. (66), using a PC-based aircraft simulator, showed that cross training was an important determinant of effective task coordination, communication, and performance. Particularly in high workload situations, cross training by positional rotation can improve team communication, particularly when tasks are highly interdependent (67).

Team Model Training

Team model training (TMT) was developed to enhance indoctrination of combat teams and can be adapted to trauma team preparation (68). TMT evolved in response to concerns that standard measures of team performance were lacking, drills were unsystematic, trainees were overloaded with details, and practice was unguided by feedback. TMT consists of a series of explicit training curricula and feedback-guided experiential learning on PC-based simulators. The goal is to foster collaborative teamwork. Results of TMT education exercises suggest that complex team interactions can be demonstrated and practiced using low-cost, PC-based simulations.

Trauma Crew Resource Management

Trauma Crew Resource Management (TCRM) derives from concepts developed in the aviation industry, called Cockpit Resource Management (CRM). From the days of the Wright brothers to the 1970s, formal training for pilots focused on the technical (stick and rudder) components of flight. In the 1970s, NASA's research showed that many commercial air crashes that occurred were not because of equipment failure or deficiencies of technical piloting skills, but because of failures of communication and teamwork (69,70). In response, the commercial aviation industry initiated a new type of pilot training, which went by the acronym CRM (for Cockpit Resource Management). CRM focused on the interpersonal aspects of flying in a multiperson crew. As the concept matured, the name, but not the acronym, changed to Crew Resource Management, reflecting the fact that safety critical interactions extend beyond the confines of the flight deck (4). By the late 1990s, CRM had evolved through five generations into a highly focused training program with the goal of managing the consequences of human error. Analogously, TCRM training enables trauma teams to effectively harness all available resources to provide the best possible patient care. TCRM facilitates the translation of individual knowledge of what needs to be done into effective team processes and helps to bring structure to the complex and chaotic world of the trauma bay.

TCRM derives from an earlier adaptation of aviation CRM to anesthesiology. Anesthesia Crisis Resource Management (ACRM), an immersive simulation-based training program, was developed by Gaba et al. (53,71) in the early 1990s. The value of ACRM resides in the realistic enactment of scenarios followed by rapid cycle and learner-centered debriefings using video analysis of the clinical team's performance. A preliminary study of the effectiveness of ACRM suggested that trainees learned powerful lessons that they attempted to incorporate into their clinical practice (72). The study coupled in-depth interviews about ACRM training with confidential debriefings about the management of actual serious incidents in patient care after trainees underwent ACRM training. Another study revealed widespread failures in situation awareness and coordination by medical teams and organizational barriers that led to patient harm, further validating the need for this type of training (73). From this pioneering work, one can delineate the essential features of TCRM training courses (Table 5). Additionally, CRM courses have been developed for other specialties, including emergency medicine (74,75) and critical care (76). In the most extensive evaluation of formal teamwork training in a medical setting to date, Morey et al. (77) described the MedTeams Project. A team-based training curriculum based on CRM principles was implemented in nine hospital emergency rooms. Team training of 684 clinicians produced

Table 5 Essential Skills Taught in Trauma Crew Resource Management Courses

Adaptability
Prioritization of tasks
Shared situation awareness and distribution of the workload
Team communication before and after patient arrival
Mobilization and use of all resources in the trauma bay that extends to the OR, intensive care unit, and diagnostic facilities
Performance monitoring and cross-checking of data and team functions
Command, communication, and coordination of feedback
Leadership and the management of the team members' followership
Willingness to challenge each other and conflict resolution skills

Abbreviation: OR, operating room.
Source: From Ref. 122.

statistically significant decreases in clinical errors and improvement in the quality of team behaviors. However, no statistical differences in patient outcomes were seen.

Simulators for Trauma Team Training and Assessment

There are substantial ethical and educational limitations to the use of patients for the clinical training of individuals and teams. The opportunities to learn and practice desired responses to uncommon events or types of injuries are limited, even in a busy trauma center. In fact, actual trauma resuscitations are not optimal training opportunities, because patient care must take precedence over teaching. Moreover, clinical events occur in an uncontrolled setting under stress and time pressure. Societal and regulatory pressures will increasingly limit the use of real patients, especially the critically ill ones, for hands-on clinical training. Simulation has been widely touted as a tool to improve clinical care through enhanced training and evaluation. Simulations can include patient actors (e.g., standardized patients) (78,79), PC-based partial task trainers (80), or full-scale realistic patient simulation (RPS) (81) (discussed below). **Computer simulation of trauma scenarios will become an essential training tool, as it has in almost every other high-risk domain, including aviation, space flight, military operations, nuclear and hydroelectric power generation, ground and sea transportation, and chemical process control (82).**

There are many benefits of medical simulation. Simulations can permit clinicians to learn new or improve old techniques safely and economically without posing harm to patients or to trainees (72,81,83). Simulations can be controlled and modulated according to the needs of a team (84). Decision-making skills can be embedded into the scenario to train for reasoning, metacognition, risk assessment skills, and responsiveness to adverse events. Guided practice with video-based feedback that incorporates measures of performance can be considered managed experience (3). Perhaps, most importantly, lessons taught in a realistic simulation environment may be retained better, on account of the required active learning and focused concentration, the greater emotional intensity of the experience, and its direct association with real-world clinical events (David Gaba, personal communication, 2001). Thus, trauma teams can train, evaluate, and become credentialed providers before participating in actual clinical activities.

Recent literature is beginning to provide evidence for the value of RPS to train and evaluate trauma teams (73,84–87). A study by Holcomb et al. (87) evaluated ten 3-trainee teams before and after a one-month trauma-center rotation, using RPS scenarios. The teams showed significant improvement on multiple measures of technical skill, supporting the face validity of RPS-based technical performance assessment. Lee et al. (88) conducted a prospective randomized controlled trial of surgical interns' trauma assessment and management skills after using either RPS or moulage practice training sessions. RPS-trained interns scored higher on trauma assessment skills and on the management of an acute neurological event.

Value of Realistic Patient Simulators

Realistic patient simulators are fully interactive physical simulations in which the responses of the device to the clinical interventions are scripted to be realistic. In the highest fidelity simulators, the mannequin's response is based on detailed physiological and pharmacological computer models. The goal is for the simulator to respond to clinical interventions in the same way a patient would respond. Thus, the participant interacts with a realistic cognitive and physical representation of the full acute care environment and thereby experiences emotional and physiological responses similar to those experienced in real patient-care situations (89,90). Realistic patient simulators consist of a computer-controlled system and a plastic patient mannequin that generates physiological signals (e.g., electrocardiogram, invasive and noninvasive blood pressure, lung sounds, palpable pulses) and allows for complex airway management scenarios (72,81,89). The mannequin's head contains a speaker so that the trainee can converse with the patient when contextually appropriate. Trainees can also query the operator as needed concerning physical signs not reproduced by the mannequin (e.g., skin color, diaphoresis). There are multiple technical, financial, and methodological issues that affect the design and implementation of RPS-based training programs (81,91). Nonetheless, patient simulators have facilitated study of the response to critical incidents (90), the occurrence of medical errors (89), the role of teamwork (75), and the effects of other factors on clinical performance (91,92).

Importance of Scenario Design

Oser et al. have outlined specific steps for developing simulated scenarios for eliciting team behaviors (93). First, skill inventories and historical performance data are reviewed to identify what should be measured. Identifying the core measurement objectives builds content validity into the scenario. Second, scenarios are created that provide specific reproducible opportunities to observe performance, related to the objectives chosen. Third, performance measures are developed that accurately and reliably assess performance on the objectives. Measures should have the ability to describe what happened (i.e., outcome measures) in addition to describing why certain outcomes were or were not attained (i.e., process measures).

Components of a Simulation-Based Training Course

A typical simulation-based training course will include some kind of pretest, preparatory didactics (lecture, web, or hands-on demonstrations), the performance of one or more standardized scripted scenarios that are videotaped, post-simulation videotape-based debriefing, and a post-training evaluation (of both the trainee and of the training experience) (94). The debriefing is the most important experience, especially when training multidisciplinary teams (82,95,96). Debriefing should occur immediately after each simulation scenario and not uncommonly lasts longer than the scenario itself. Participants debrief together as a team with peers providing feedback.

EVALUATING TRAUMA TEAM PERFORMANCE

Assessing team performance will be key to understanding ways to improve team performance and increase patient safety (Table 6). There is a consistent argument in the literature that team process and outcomes must be distinguished (97). Process is defined by the activities, strategies, responses, and behaviors employed by the team during task accomplishment, while outcomes are the clinical outcomes of the patients cared for by the team. Process

Table 6 Questions to Ask When Assessing a Trauma Team's Performance

Is the team the right size and composition?
Are there adequate levels of complementary skills?
Is there a shared goal for the team?
Does everyone understand the team goals?
Has a set of performance goals been agreed upon?
Do the team members hold one another accountable for the group's results?
Are there shared protocols and performance ground rules?
Is there mutual respect and trust between team members?
Do team members communicate effectively?
Do team members know and appreciate each other's roles and responsibilities?
When one team member is absent or not able to perform the assigned tasks, are other team members able to pitch in or help appropriately?

measures are important for training when the purpose of performance measurement is to diagnose the problems and to provide feedback to trainees. Until recently, the medical community has focused more on outcomes than on process. Medical educators have begun to appreciate the competencies that define effective team process. The key is to identify and measure processes that are directly related to patient outcomes (e.g., successful resuscitation). Measurement tools must be reliable and valid and must distinguish between individual and team-level deficiencies. Most importantly, the results of the assessment must be translatable into specific feedback that will enhance team performance (98).

Paucity of Validated Competency Assessment Metrics

There are a variety of methods to evaluate team performance including debriefing with or without the use of videotaping, simulation with or without standardized patients, and the use of trained observers. Although metrics are available in nonmedical domains, there are very few well-defined validated metrics to assess competency in complex clinical team activities such as trauma resuscitation. No rigorous evaluation studies have been undertaken that relate the training experience with actual clinical outcomes, thereby validating metrics for assessing team performance.

Video Analysis of Trauma Care

Video analysis of team performance is an extremely valuable training tool because it removes any challenge to factual events, helps trainees clearly visualize each event, and can be used as a permanent record or an archive for future educational activities. Beginning with the experience of Hoyt and Shackford (99) in the late 1980s, videotaping and review of resuscitations has become a standard quality assurance method for many trauma centers. Subsequent work has confirmed benefits from improved team education and training, more efficient and accurate QA processes, interventions to improve care processes, and better patient survival (32,100). In a study of simulated anesthetic crises, trainees' review of videotape of the events led to decreases in "time to treat" and workload in subsequent simulations (101). Recently, Scherer et al. (102) found that video-based feedback of trauma resuscitations reduced disposition time by 50%.

However, videotaping of patient care requires overcoming substantial obstacles including medicolegal issues, confidentiality, logistical and resource issues (103,104), and analytical limitations (105). Nevertheless, the ability of multiple instructors to score performance from videotape allows the evaluation of the reliability of performance-assessment metrics. In a simulation-based study, investigators used videotape to validate a systematic rating system of behavioral and clinical markers, with the objective of creating a foundation for team training and assessment programs (106).

EYE TO THE FUTURE

Team training based on CRM principles are being widely disseminated in multiple civilian and military hospitals (77). It would not be surprising for these principles to be incorporated into ATLS and Advanced Cardiac Life Support® (ACLS®) training in the near future. In addition, future team-training programs are expected to incorporate a wider range of educational principles and goals (107). Within a few years, virtually all academic medical centers will have dedicated simulation centers that will increasingly conduct multidisciplinary team-training courses (86).

Increased Emphasis upon Computerized Simulation

Training for rare or dangerous events (e.g., ATLS and ACLS) can and should be increasingly facilitated by computerized simulators (108). The progression toward simulation-based training was recently endorsed by the American College of Surgeons' Committee on Trauma, with their approval of the use of torso simulators during the skills section of ATLS training. Although patient simulators are not currently approved for the assessment-training portion of ATLS, this is likely to occur in the near future. Indeed, patient simulators provide some advantages over moulage actors (e.g., physiological modeling of the scenario and immediate response to therapy) (88).

Patient simulators have been shown to improve both diagnostic and therapeutic decision-making during ATLS training of surgical interns (109). Not only did simulator training speed the acquisition of trauma management skills but, just as importantly, morale was improved. Indeed, the surgical interns participating in the study deemed the simulation training to be worthwhile, and also attributed to the simulation training their improvement in both self-confidence and individual competence (109).

A separate observational study showed that simulators were effective in training junior surgery residents during their critical care rotation (110). Three scenarios were tested. None of the residents successfully completed the first scenario. Subsequent performance improved in previously neglected areas. Although the simulators were useful in identifying the residents with large knowledge deficits, the greatest utility was in evaluating deficiencies in the training program itself (110).

Military and civilian prehospital personnel may benefit from simulation training as well. Currently available hospital-based scenarios can be easily modified to include variations in light, sound, available assets, and numbers of casualties. In addition, simulations can be linked together to replicate mass casualty events, and these simulations can be used to evaluate the management decisions of larger teams and commanders from remote locations (87).

Incorporating Military and Aviation Industry Lessons

Besides placing increased emphasis on computerized simulators for rare event training, the trauma community could significantly improve resuscitation team training by looking to Crew Resource Management (CRM) and other team-training strategies that have already been developed in other domains. The tactical decision making under stress (TADMUS) project, conducted in the surface vessel community of the U.S. Navy, has produced a number of useful tools and lessons learned, which are applicable in health care (107). Based on our experience, as well as a review of the literature, we make the following recommendations for trauma and critical care team training.

First, the health care community should develop a standard set of generic teamwork-related knowledge, skills, and attitude competencies. These competencies would represent the core elements of successful teamwork in health care. This would begin to establish a common language for describing teamwork in health care.

Second, instructional designers should look beyond aviation CRM training to all available training research and tools. For example, Salas and colleagues (66) have compiled an extensive collection of principles and guidelines for assertiveness training, cross-training (66), stress management training (111), and team self-correction (112). Current medical team training programs rely almost entirely on classroom-based or simulator-based training methods, rather than choosing from a variety of instructional strategies to complement the specific training content. With few exceptions, new advances in training technology—such as computer-based partial-task training, low-fidelity simulations, embedded training, scenario-based training, high fidelity robotic and virtual reality training—have rarely been used, despite growing evidence regarding their effectiveness (113). Recent advances in training theory—such as the effect of pre- and post-training factors on training outcomes, the effect of practice schedules on skill acquisition and retention, and the critical role of individual differences in shaping trainees' motivation—have similarly been ignored (68,113–115).

Third, many experts believe that, in the next 5 to 10 years, all clinicians will be required to train and be credentialed on simulators before practicing on patients. Indeed, computer-based simulations were formally introduced for certification by the U.S. Medical Licensure Examination (USMLE) in November 1999 as the official Step 3 Primum® exam (116). It is likely that these exams will soon evolve into full simulation scenarios and may one day be conducted in simulation centers. Indeed, simulation centers have already been used for remedial training of anesthesiologists by the New York Society of Anesthesiologists Committee on Continuing Medical Education and Remediation (117). In addition, physician graduates of an ATLS course recently demonstrated more improved technique and function, following a simulator session than those who did not receive such training (118). Similarly, physicians, nurses, and respiratory therapists (all ACLS certified within two years of their simulation training) showed improved ACLS task-completion rates ($p = 0.001$) following simulator training (119).

More intriguing is the advancing sophistication of virtual (or immersive) reality simulation. Future trauma teams may practice in a virtual world of animated three-dimensional patients and care environments while interacting with simulated clinical tools that provide realistic tactile feedback (see, for example, virtual reality training environments provided by "hit lab research" (120).

Finally, video review of patient care continues to gain popularity for training as well as quality improvement (102,104,121). It would not be surprising for all care areas to ultimately be continuously monitored with audio, video, and physiological data capture to facilitate on-going performance improvement as well as adverse event analysis (analogous to aviation's cockpit flight recorder). Fostering effective teamwork will remain a focus of healthcare performance improvement because the resulting attitudes, skills, and behaviors are essential to establishing a culture of safety and quality.

SUMMARY

Teams make fewer mistakes than do individuals, especially when all team members know their individual responsibilities as well as those of the other team members. However, simply bringing individuals together to perform a specified task does not automatically ensure that they will function as a team. Trauma teamwork depends on a willingness of clinicians from diverse backgrounds to cooperate toward a shared goal, to communicate, to work together effectively, and to improve. Each team member must be able to: (*i*) anticipate the needs of the others; (*ii*) adjust to each other's actions and to the changing environment; (*iii*) monitor each other's activities and distribute workload dynamically; and, (*iv*) have a shared understanding of accepted processes, and the knowledge of how events and actions should proceed.

Teams outperform individuals especially when performance requires multiple diverse skills, time constraints, judgment, and experience. Nevertheless, most people in health care overlook team-based opportunities for improvement because training and infrastructure are designed around individuals. Teams with clear goals and effective communication strategies can adjust to new information with speed and effectiveness to enhance real-time problem solving. Individual behaviors change more readily on a team because team identity is less threatened by change than are individuals. Behavioral attributes of effective teamwork learned on the trauma team, including enhanced interpersonal skills, can extend to other clinical arenas.

Turning trauma care experts into expert trauma teams requires substantial planning and practice. There is a natural resistance to move beyond individual roles and accountability to the team mindset. One can facilitate this commitment by: (*i*) fostering a shared awareness of each member's tasks and role on the team through cross-training and other team-training modalities; (*ii*) training members in specific teamwork skills such as communication, situation awareness, leadership, followership, resource allocation, and adaptability; (*iii*) conducting team training in simulated scenarios with a focus on both team behaviors and technical skills; (*iv*) training trauma team leaders in the necessary leadership competencies to build and maintain effective teams; and, (*v*) establishing and consistently utilizing reliable methods of team performance evaluation and rapid feedback.

ACKNOWLEDGMENTS

Dr. Barach would like to acknowledge the administrative support of Roxanna Araya. The author's time on this project was supported in part by the American Heart Association (grant #0330274 N) and a contract from the Agency for Health Care Research and Quality (AHRQ, Rockville, MD, U.S.A.).

Dr. Weinger would like to acknowledge the editorial support of Karen Ruberg and Kelly Vo. The author's time on this project was supported by grants from the AHRQ (R01-HS11521 and P20-HS11750) and the Department of Veterans Affairs (HSR&D IIR 20-066; Washington, D.C., U.S.A.).

KEY POINTS

- Effective teams possess five characteristics of success (the five Cs): commitment, common goals, competence, consistency (of performance), and communication (16).
- Studies show that the presence of a single identified trauma resuscitation team leader leads to a better secondary survey, ATLS guideline adherence, and team coordination (32).
- Human factors (also called ergonomics) is the study of human interactions with tools, devices, and systems with the goal of enhancing safety, efficiency, and user satisfaction.
- High noise levels create a positive feedback situation, where noisy rooms require louder voices and higher volume alarms leading to increased noise levels, missed clinical events, and greater team dysfunction.
- Trauma team members must make special efforts to communicate clearly and unambiguously, especially when members of the team are new or less experienced.
- Effective teams adapt to changes in task requirements, anticipate each other's actions and needs, monitor the team's ongoing performance, and offer constructive feedback to other team members (61).
- Trauma Crew Resource Management (TCRM) derives from concepts developed in the aviation industry, called Cockpit Resource Management (CRM).
- Computer simulation of trauma scenarios will become an essential training tool, as it has in almost every other high-risk domain, including aviation, space flight, military operations, nuclear and hydroelectric power generation, ground and sea transportation, and chemical process control (81).
- Video analysis of team performance is an extremely valuable training tool because it removes any challenge to factual events, helps trainees clearly visualize each event, and can be used as a permanent record or an archive for future educational activities.

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Transport of the Trauma Patient

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INTRODUCTION

The movement of critically injured patients is potentially hazardous. However, significant improvements in transport safety and efficiency have occurred over the last decade chiefly because of the advances in resuscitation algorithms, training, and monitoring technology. Onboard resuscitation capabilities and transport logistics have also progressed. Because each phase of trauma management is improving, transport teams are being tasked with the transport of increasingly severe injuries.

In civilian trauma settings, the focus is centered upon getting the patient to the trauma center as quickly and as safely as possible. In military situations, additional factors (i.e., enemy fire, large distances between injury and surgical care) complicate transport logistics. In both military and civilian mass casualty situations, injured patients may first undergo field triage and stabilization (Volume 1, Chapter 4). Transport of injured patients in a combat or hostile environment requires not only a timely and efficient medical evacuation, but also consideration of the tactical status of the location where the casualty occurred. The time spent devoted to field stabilization prior to transport depends upon the patient's condition, the field conditions, and the organization of the trauma system. The relative merits of field stabilization ("stay and play") versus immediate transport ("scoop and run") are covered in Volume 1, Chapter 4.

This chapter focuses only upon the numerous transportation considerations for prehospital, interhospital, and (to a lesser degree) intrahospital patient transfers. Both civilian and military considerations are reviewed throughout. This chapter surveys the various modes of transport (i.e., ground, rotary-wing, fixed-wing, etc.) and provides suggested equipment and training requirements. In addition, the physiological perturbations that occur with various forms of transport are examined. During long-range travel preparation, anticipation of complications and training to deal with these eventualities becomes even more important. Special transport circumstances are reviewed including mass casualties and combat zone evacuations. Transport for patients injured by weapons of mass destruction (WMD) can present additional complications. Following the events of 11 September 2001, it has become evident that civilian care providers, like their military counterparts, need to possess basic knowledge and training in disaster and mass casualty management involving WMDs. These topics are also covered in this chapter.

Overview

Prior to the 1960s, trauma transport was haphazard, as were trauma systems in general (1). Civilian prehospital transport had traditionally been provided by ground ambulance services which were generally operated by private funeral homes. Although many ambulance crews were trained and reputable, there are reports of some drivers who would arrive at a scene of an accident and prefer to pick up the dead because they were more likely to be paid (2).

The modern era of emergency medical services (EMS) in the United States can be traced to a seminal publication by the National Academy of Sciences in 1966, which described the poor state of affairs in the EMS at that time. The publication provided a blueprint for improvement of transport and quality of care for trauma patients (1). In the late 1960s and throughout the 1970s, widespread funding was made available through the U.S. Department of Transportation and the U.S. Department of Health, Education, and Welfare to develop EMS, thereby resulting in improved trauma transport systems and the establishment of over 300 regional trauma centers.

The success of air evacuation experienced by the military (starting in WWII with fixed-wing aircraft and later during the Korean and Vietnam conflicts with helicopters) led to widespread application of helicopter transport in civilian prehospital trauma care (3–5). However, several recent studies of large statewide or regional systems have shown that the use of helicopters for on-scene transport of trauma patients does not influence survival in most urban settings (6–9). The explanation for the disparity between the utility of prehospital air evacuation in military applications and the variable benefits produced by this modality in civilian practice is multifactorial. Although a complete review is beyond the scope of this chapter, some of the less disputed differences are as follows: first, in the military setting, safe transport out of the combat zone may be impossible without air transport (thus air evacuation equates to the only chance for survivial). Second, in the civilian environment, the tendency is to "over-triage" from the field, which leads to artificial bias in comparisons of injury severity and resource utilization. Third, ground ambulance is often a quicker mode of patient delivery to the hospital in urban settings where distances are short and where it can be potentially more difficult to locate a "landing zone" in proximity of the scene.

In civilian practice, the greatest role for helicopter use for medical evacuation from field emergencies is when the prehospital transport distances are great and/or the geographic barriers are significant (e.g., mountains, rivers, or washed-out roads separate victims from the hospital). In these situations, air transport will significantly reduce the travel time and substantially increase the survival of critically injured patients.

The duration of the prehospital interval (the elapsed time between the initial injury and arrival at the hospital) can have a direct impact on patient survival, especially when the patient has a life-threatening injury requiring immediate surgical intervention (e.g., ruptured spleen, severe closed head injury, or a major retroperitoneal hemorrhage requiring internal iliac artery embolization, etc). In any case, less time spent with extrication, triage, and stabilization at the scene, (Volume 1, Chapter 4), and less time spent during transport to a receiving hospital or trauma center, generally results in better outcomes.

Transportation Guidelines

Guidelines for transport within the hospital (intrahospital) and between hospitals (interhospital) have been formally developed by the American Society of Anesthesiologists (10), the American College of Surgeons Committee on Trauma (11), and the Society of Critical Care Medicine (12), among others. Three common themes emerge with all of these guidelines: (*i*) patient transport always involves some degree of risk, (*ii*) the benefits to be realized must outweigh these potential risks, and (*iii*) during transport, the standards of care (especially monitoring) should be at the same level or higher than that provided in the setting from which the patient is being transported.

The level of care during transport should be equal to or exceed the level of care the patient is receiving prior to departure.

Figure 1 shows the transport of a patient with life-threatening respiratory failure from the surgical intensive care unit (SICU) to the operating room (OR). This patient is maintained on extracorporeal life support (ECLS). The transport team consists of the anesthesiologist, the ECLS attending, the ECLS perfusionist, the bedside critical-care nurse, and the respiratory therapist. Patients like this are entirely dependent upon machines and drugs to maintain hemodynamic and respiratory function. Although loss of any one of these numerous supportive devices would be lethal, these patients can be transported within the hospital when necessary. Indeed, patients requiring this level of care are transported on a daily basis within hospitals and occasionally between hospitals in numerous areas around the world. Some centers (e.g., University of Alabama and University of Michigan) specialize in the transport of critically ill patients and do it frequently.

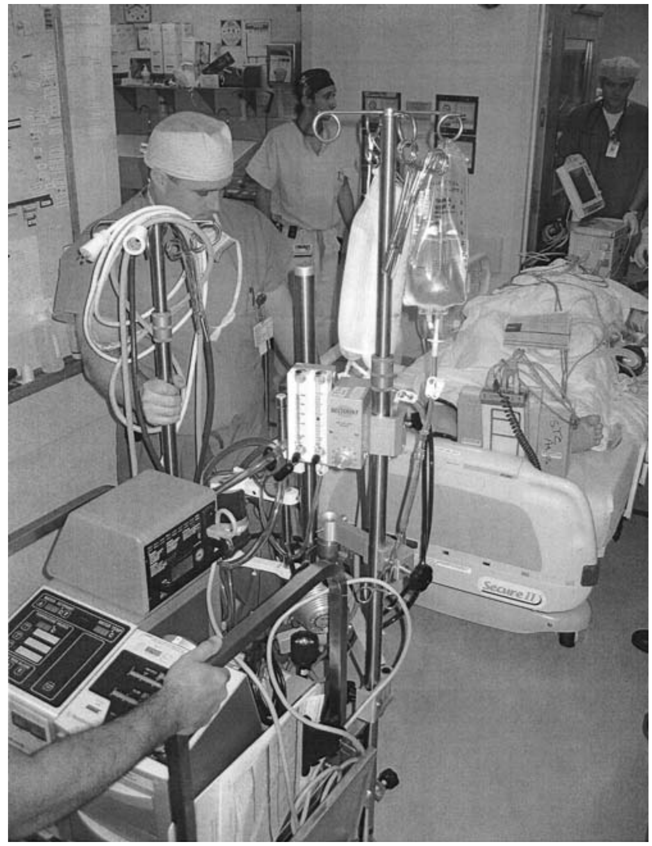

Figure 1 Intrahospital transport of a critical care patient on extracorporeal life support (ECLS). The transport team consists of the anesthesiologist, the ECLS physician, the operating room transport nurse, the critical care nurse, and the respiratory therapist. Each monitors their responsibilities during transport from the surgical intensive care unit to the operating room. *Source*: Courtesy of Maureen McCunn, Maryland, U.S.A.

In military transport of critically ill patients, critical care air transport teams (CCATT) are utilized by the air force. From Iraq and Afghanistan, the CCATTs transport the patient from the in-theatre combat support hospital (CSH) to a higher level of care in Landstuhl, Germany.

Determining Appropriateness of Transport

Severely injured patients in both civilian and military settings will require urgent transport to the hospital. Thus, the need to move the patient is self-evident. However, patients already located inside a hospital may require intrahospital transport for evaluation and treatment or interhospital transport to receive a higher level of therapy not provided at the hospital (e.g., transfer to a burn center). **Patients should be moved from one area of care to another only if the expected benefit of the transport (diagnostic procedure or operative management) exceeds the transport risk.**

In determining the appropriateness of intrahospital or interhospital transport, safety and benefit issues have been assessed in a recent review by Stevenson et al. (13). The authors summarize the major findings in the available transport literature and conclude that, although transport is associated with physiological changes in patients, case-controlled matching demonstrates that these alterations in vital signs are often not different from changes that may have occurred in the patient without movement from their existing location (i.e., within the SICU). However, monitoring must be optimized during transport to detect alterations before harm occurs.

The transport personnel must assume that perturbations in the patient's status will occur during transport and be prepared for these changes.

Being prepared to manage perturbations in patient status requires experience and training and a high level of monitoring, as well as the ability to make therapeutic interventions during transport. The latter requires continued availability of resuscitation equipment, drugs, and the presence of appropriate personnel during the transport.

PREHOSPITAL AND INTERHOSPITAL TRANSPORT MODES

In combat situations, rotary-wing aircraft are often used for initial evacuation and transport to a receiving hospital. In civilian practice, ground ambulance is most commonly used. For interhospital transport, all three modes (ground ambulance, rotary-wing aircraft, and fixed-wing aircraft) are used. In special circumstances, other modes such as human carriage, mule trains, cars and taxis, trucks, buses, locomotive trains, or watercraft can be adapted for patient transport. Each transportation modality has strengths and weaknesses, as outlined in Table 1.

Ground Travel

Ground ambulance is the most widely used mode of transportation because of its simplicity and widespread availability (Fig. 2). **Ground ambulances can be configured to closely duplicate the capabilities found in the trauma bay and in the SICU.** The major disadvantage of a ground ambulance is the long time it takes to cover large distances, increasing the patient's exposure to the risks of transport. When the travel distances are relatively short and open roadways are available, ground transportation is safer and more cost efficient, without any diminution in patient outcome (8). Shatney et al. (9) reported a retrospective review of 947 consecutive trauma patients transported to their urban trauma center, finding that 33.5% of patients transported by helicopter were discharged directly from the emergency/casualty department and not admitted to the hospital (i.e., "over-triage") and that few of those in need of urgent transport benefited beyond the care they would have received if transported by ground.

Table 1 Modes of Transport

Mode	Advantages	Disadvantages
Ground ambulance	Simple to operate and maintain, and generally available Best for short distances (5–10 miles), quicker to and from the scene	Unable to cross geographical barriers (i.e., mountain ranges, flooded roadways Slower for travel of long distances. Less safe in hostile territory
Rotary-wing aircraft	Short range, runway not required Airport not required Can land in hostile territory, or difficult terrain Best for 50 to 150 miles Useful in search and rescue, some models can be refueled in midair	High cost and complex to operate Inefficient for disasters with large number of casualties (only small number of patients transported at a time)
Fixed-wing aircraft (small)	Faster runway to runway travel Uses shorter, unimproved runways Best for 150 to 300 miles	High cost and complexity Aircraft may be better utilized in the disaster area for other purposes
Fixed-wing aircraft (large)	Advanced en route care is facilitated Carries more patients Long range missions possible (e.g., >20 hr with aerial refueling) More efficient medical crew can manage multiple patients Best for >300 miles	Very high cost and complexity Longer, improved runways required Requires detailed planning and coordination between sending, evacuation, and receiving medical teams
Military fixed-wing In-theatre Medevac patient transport: C-130 (unrefueled range 1500 nautical miles)	Rugged design Capable of landing and takeoff on dirt runways Best for intratheater transport of multiple casualties 75 to 750 miles	Noisy, bumpy Often very tight quarters Although the plane often survives in hostile territory, the patients and passengers can "experience violent conditions"
Military fixed-wing transcontinental Medevac patient transport: C-17 (unrefueled range 5200 nautical miles)	Capable of steep take-off and landings Requires relatively short runway (3000 feet) Best for intercontinental medevac and patients transport	Few disadvantages when used for intended purpose If forced into action for short distances (<150 miles) may not be fuel efficient

Figure 2 Custom-designed motor vehicle for civilian ground transport of critically ill trauma patients. (**A**) Side view: large converted panel truck vans such as this can carry multiple patients simultaneously when outfitted and staffed to do so. (**B**) Interior view: the monitoring and communication station in foreground and patient resuscitation and monitoring in the background. *Source*: Courtesy of Maureen McCunn, Maryland, U.S.A.

Rotary-Wing Transport

Rotary-wing aircraft offer a significant speed advantage over intermediate distances (50–150 miles), as well as when road conditions interfere with safe or rapid transport (Fig. 3). **Civilian interhospital transfers and prehospital transport in urban areas have not been shown to benefit from helicopter transport (14,15).** Although emergency patient transport by any conveyance method contains hazards, the use of rotary-wing aircraft carries additional risks for the crew and the patient not usually encountered with other transport modalities. Indeed, a significant and continued increase in the number of medical helicopter accidents occurred during a recent 10-year survey of civilian medical helicopter service (16). Hospitals offering air transport should have an adequate area for helicopter landings, simplifying the transfer from the hospital to the vehicle. Drawbacks include increased cost and complexity and limited ability to operate in adverse weather conditions compared with a ground ambulance.

The noise, vibration, and available space in the cabin of a typical rotary-wing aircraft make patient assessment and treatment far more challenging (Fig. 3B). However, during certain disaster scenarios, helicopter transport may represent the only viable form of prehospital delivery or intrahospital transport. For example, following Hurricane Katrina, New Orleans roads were flooded in 80% of the city, obviating ground rescue and transport. Hospital evacuations were accomplished using combinations of helicopters (Fig. 4A), boats (Fig. 4B), which then transferred patients to either ambulances or rotorcraft (Fig. 4C) for completion of evacuation to the major staging areas (Fig. 4D) and then to Louis Armstrong New Orleans International Airport where fixed-wing aircraft were used to transport patients out of the city (Fig. 4E).

Fixed-Wing Transport

Fixed-wing aircraft are most beneficial when transporting patients over long distances (usually >300 miles for large planes), as may be required when the patient is located in a remote area, or when highly specialized care is required for a rural-based patient. As with rotary-wing aircraft, airplanes are expensive and complex to operate. Furthermore, there is comparably less landing flexibility, as these aircraft must operate from an airfield, requiring an additional transfer involving a ground ambulance to ferry the patient between the airplane and hospital. Finally, a fixed-wing aircraft typically operates at higher altitudes and presents additional physiological stresses during flight (discussed later in the chapter).

Miscellaneous Modes of Transportation

Hospital ships and smaller ambulance boats are also used for transport of injured patients over waterways and sea. In general, boats are slower than other motorized modes of transportation. However, in certain regions of the world

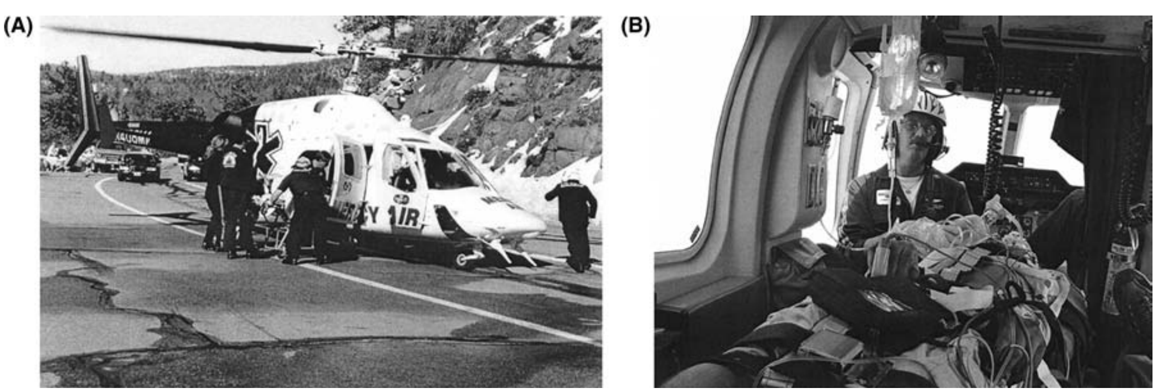

Figure 3 Civilian life-flight helicopter set-up for transport of critically ill trauma patient. (**A**) Shows landing on road in San Bernardino mountains. Highway patrol holds traffic while patient is loaded. (**B**) Inside view: tender in position to manage the airway. Patient is intubated and mechanically ventilated. Both (**A**) and (**B**) show Bell 222 Model B rescue helicopter. *Source*: Courtesy of Kelly Forman, Mercy Air Medical Services, Rialto, California, U.S.A.

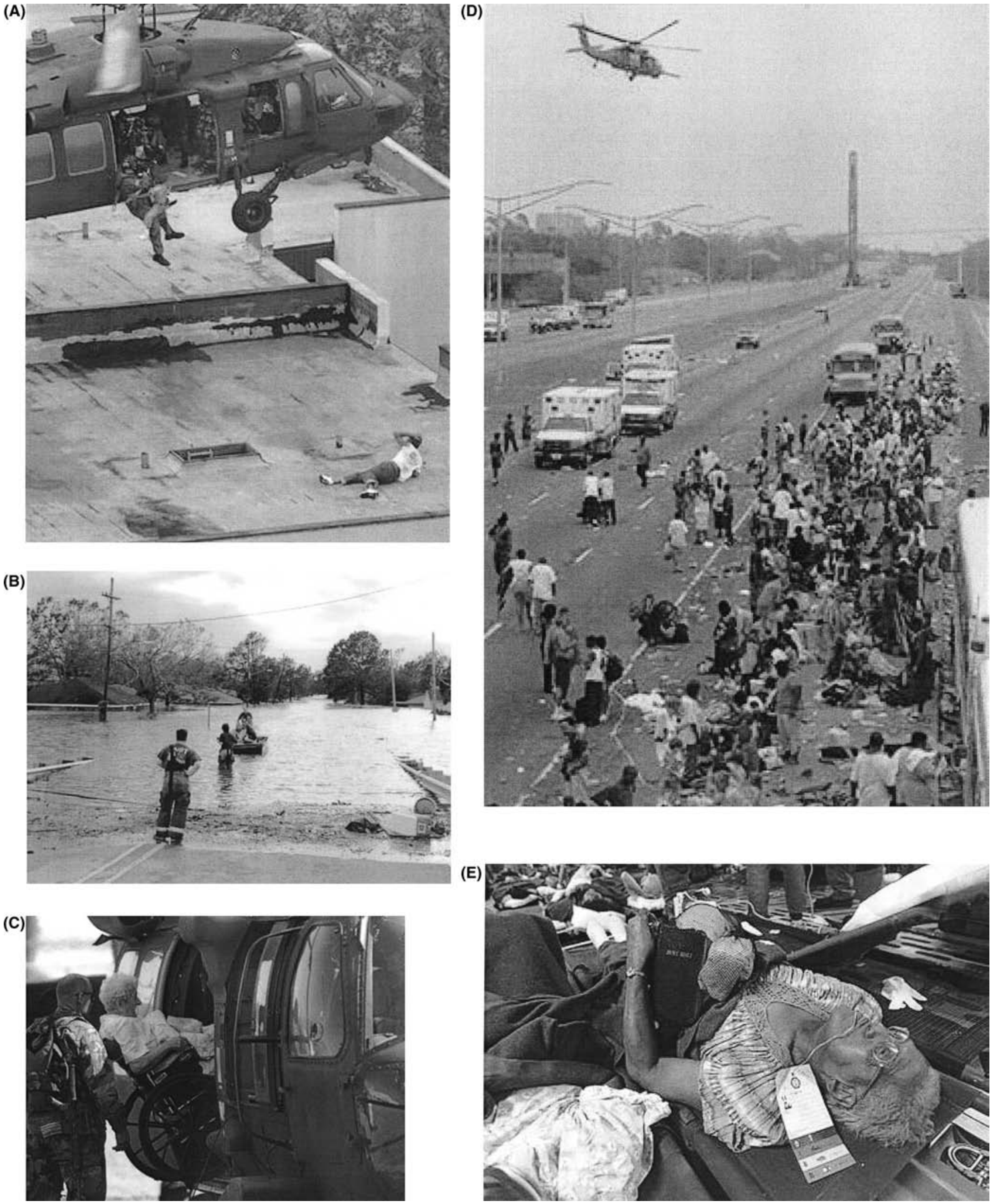

Figure 4 Rescue and evacuation of Hurricane Katrina victims. (**A**) Roof rescue. (**B**) Boat rescue worker. (**C**) Loading wheelchair victim into helicopter. (**D**) Staging area with triage centers (not shown). (**E**) Evacuation by air force cargo plane.
Source: Courtesy of the U.S. 5th Army.

with long shore lines, or large concentrations of island archipelagos, combinations of ground ambulance and ferry (for short distances) may be the quickest method of casualty transport.

In many low-income nations, prehospital transport commonly occurs in carts or on animals and may cover extremely long distances. Public transportation is also used when the injured do not have access to ambulance services or cannot afford to pay with cash. Basic first-aid training of private vehicle drivers in middle-income countries and of citizens in low-income countries has been shown to decrease mortality (17,18).

PREPARATION

Transport Team Members

The personnel needed to ensure safe transport can vary depending upon patient characteristics and destination issues as shown in Table 2. The optimum composition of the transport team is defined by a combination of features including the complexity of transport, equipment required, whether the transport is pre-, intra-, or interhospital, as well as established hospital, state, or military policies. For example, the U.S. Air Force CCATT is staffed by an intensivist physician, a critical care or emergency medicine nurse, and a cardiopulmonary technician.

The transport team leader should be trained to manage patients of all ages and be prepared to deal with a multitude of acute trauma and medical conditions. Additional team members should also be experienced in the transport of critically injured patients.

Equipment

The equipment required varies depending upon the level of care provided during transport (Table 3). The equipment suggestions listed in Table 3 are general guidelines only, and each transport should be individualized to the patient and situation. **In all cases, standards during transport must match the minimum care provided prior to transport.** Additionally, all patients must be assured to have adequate oxygen supply for the expected duration of the transport, and a backup supply must be available (discussed subsequently). A functioning suction device with tubing and a Yankauer (tonsil) suctioning tip is also mandatory. A self-inflating resuscitation bag (e.g., bag-valve-mask, Ambu®) is capable of delivering at least 90% oxygen as a means of positive pressure ventilation. Basic minimum monitoring equipment includes pulse oximetry, electrocardiography (ECG), blood pressure (BP), and core temperature monitoring devices.

A combined patient transport, monitoring, and support system has recently been introduced into the marketplace and is termed the Life Support for Trauma and Transport (LSTAT®), (Integrated Medical Systems, Inc., Signal Hill, California, U.S.A.). This platform integrates a ventilator, onboard oxygen, fluid infusors, suction, defibrillators, blood chemistry analyzer, physiological monitoring, data logging, and a portable power supply in a self-contained unit (Fig. 5). The LSTAT has been employed by international military communities since 1998 and is currently in use in Afghanistan and Iraq by some U.S. military units. The LSTAT has recently been evaluated for intrahospital transport at LAC-USC Medical Center where it was found to be safe and able to decrease staffing during movement of complex patients (19).

Long-range transport requires a more complex preparation. In addition to personnel, monitoring capabilities and equipment availabilities are also important to ensure safest transport. At a minimum, transport equipment tools should include airway tools, basic resuscitation medications, abundant oxygen, resuscitation fluids, and other supplies.

Safety Considerations

The following five factors (summarized in Table 4) must be considered when assessing the safety of emergency (prehospital), and usually less-urgent (interhospital) transport of critically ill patient:

1. In emergency transport from combat zones, resuscitation and stabilization may not be possible before evacuation and, by necessity, must occur en route. In civilian practice, the relative emphasis on pretransport resuscitation and stabilization is dictated by local practice (Volume 1, Chapter 4) and the severity of injuries, whereas interhospital transport should only occur after adequate resuscitation and stabilization has been achieved (20–22).
2. Early trasport is the critical goal of prehospital care, because the major causes of early morbidity and mortality are exsanguination and neurological injuries. Interhospital transport should only occur after the patient is stabilized (as above), all life-threatening injuries are diagnosed, and the patient is at least provisionally treated (22). **In elective settings, "early transport" means to do so before secondary problems occur (e.g.,**

Table 2 Personnel Required for Transport[a]

Personnel	Prehospital	Interhospital	Intrahospital
Patient care	Paramedic, corpsman, physician (Europe)	Critical care nurse or physician	Anesthesia provider or critical care nurse (plus one additional person) +/− respiratory therapist +/− physician
Physical transport of patient	EMT, fireman, military personnel	EMT, paramedic	Additional person (nurse, orderly, etc.)
Emergency vehicle operator	One driver—ambulance; pilot and co-pilot if air (rotary and fixed wing)	One driver—ambulance; pilot and co-pilot if air (rotary and fixed wing)	Not required
Optimum but often unavailable	Physician	Physician	Physician
Optional	Respiratory therapist	Respiratory therapist	Respiratory therapist

[a]Will depend upon degree of illness/injury and length of transport.
Abbreviation: EMT, emergency medical technician.

Table 3 Suggested Equipment for Various Levels of Transport

Basic transport[a]	Advanced transport[b]	High level transport of critically ill patients[c]
Oxygen cylinder	Oxygen cylinder	Oxygen cylinder with backup supply
"Self-inflating bag"[d] with PEEP valve, facemask, oral airways	"Self-inflating bag"[d] with PEEP valve, facemask, oral airways	"Self-inflating bag"[d] with PEEP valve, facemask, oral airways
Stethoscope	Stethoscope	Stethoscope
Assorted laryngoscope blades, endotracheal tubes, tape, CO_2 detectors, suction machine	Assorted laryngoscope blades, endotracheal tubes, tape, CO_2 detectors, suction machine	Assorted laryngoscope blades, endotracheal tubes, tape, CO_2 detectors, suction machine
Pulse oximeter	Pulse oximeter	Pulse oximeter
ECG monitor	ECG monitor	ECG monitor
BP monitor	Transport ventilator	Transport ventilator
—	Invasive monitors (PA catheter, ICP)	Invasive monitors, arterial (ALINE) (PA catheter, ICP)
Transport ventilator	Transport ventilator or ICU ventilator or LSTAT®	ICU ventilator with battery pack
Intubation drugs, emergency resuscitation drugs	Intubation drugs, emergency resuscitation drugs	Intubation drugs, emergency resuscitation drugs
ACLS® drugs	ACLS® drugs	ACLS® drugs
—	Extra bags of vasoactive infusions	Extra bags of vasoactive infusions
—	Infusion pumps	Infusion pumps
Blood products, as needed	Blood products, as needed	Blood products, as needed
No lab	No lab or LSTAT® blood sampling	Portable blood gas and electrolyte machine
Additional interhospital equipment		
Suction	Suction	Suction
—	—	Bronchoscope
Defibrillator	Defibrillator	Defibrillator
—	Chest tubes	Chest tubes
—	Ventilator with battery pack and backup ventilator	Ventilator with battery pack and backup ventilator

[a]Assumes mechanical ventilation in a stable patient.
[b]Assumes mechanical ventilation, vasoactive infusions, and full invasive monitoring in a potentially unstable patient.
[c]Assumes high-level mechanical ventilation, vasoactive infusions, and full invasive monitoring in a patient with imminent life-threatening disease and multiple organ support.
[d]Example: Ambu® bag.
Abbreviations: ACLS®, Advanced Cardiac Life Support; ECG, electrocardiogram; ICP, intracranial pressure; ICU, intensive care unit; LSTAT®, Life Support for Trauma and Transport; PA, pulmonary artery; PEEP, positive-end expiratory pressure.

infection, sepsis, and acute respiratory distress syndrome), which make transport more dangerous.

3. Patient stability is nearly impossible to assure immediately following injury. However, in the less-urgent interhospital transport setting, physicians (or other members of the transport team) should possess the training necessary to keep the patient stable during transport (23–25). If the patient requires intravenous infusions (including inotropes and/or pressors for cardiovascular support), administration of these drugs should continue during transport and those requiring mechanical ventilation should not be weaned to extubation immediately prior to transport (23).
4. Specialized transport teams improve safety (22,26). Although combat situations can preclude the presence of specialized trained personnel at the first level of care, the "medical evacuation (MEDEVAC)" care beyond that point typically involves such teams. Most civilian prehospital systems also have specialized teams, but financing for his capability is variable. Accordingly, some less-wealthy countries or states do not provide this level of care. When trained professionals are not available, as in some low-income nations, commercial drivers have been educated to provide basic first aid, which has improved prehospital care and survival for some of these trauma victims (27). Even in the absence of formal EMS, improvements in the process of prehospital transport care are possible by building upon the existing, although informal, patterns of prehospital transport. Elective civilian transport between hospitals (which can be scheduled to occur during daytime working hours) should always include transport teams with specialized training when possible.
5. Physician accompaniment improves patient outcomes (20,22). Although not always practical (especially in prehospital and combat evacuation settings), physician accompaniment increases the quality of care, and the likelihood that complications occurring during transport will be appropriately managed.

POTENTIAL TRANSPORT COMPLICATIONS

Anticipating complications and devising diagnostic and treatment plans to remedy life-threatening conditions en route should be routine practice for transport teams.

(A) (B) (C)

Figure 5 Life Support for Trauma and Transport (LSTAT®) device, manufactured by Integrated Medical Systems. Inc., Signal Hill, California, U.S.A. The LSTAT is an individualized portable intensive care system and surgical platform providing resuscitation and monitoring capability during transport. It is designed for use throughout the evacuation and treatment process. The third generation LSTAT, Model 9602 (shown), contains a ventilator, suction, oxygen system, infusion pump, physiological vital signs monitor (including invasive lines), clinical blood analyzer, and defibrillator. These systems are integrated into a network-capable onboard computer. The device has a stand-alone power system and is configured to NATO litter dimension requirements. (**A**) End view showing the display screen, oxygen supply, and suction apparatus. *Source*: Courtesy of José A. Acosta, South Eastern Afghanistan, 2005. (**B**) Onboard USS Peleliu showing evacuation of marine to waiting UH-60 chopper. *Source*: Courtesy of U.S. Navy. (**C**) In FST tent, similar to that shown in Volume 1, Chapter 5 (Figs. 5–12 and 5–13). *Source*: Courtesy of Integrated Medical Systems, Signal Hill, California, U.S.A.

Adverse changes in vital signs that occur during transport have been described in detail (28–31). These include significant changes in heart rate, BP, oxygenation, CO_2 exchange, and dysrhythmias. The mechanism of injury and the current clinical state of the patient should guide the decision-making processes in diagnosing and managing acute changes in patient status. For example, new onset of hypotension, encountered while transporting a patient from the field to the trauma center following a gunshot wound to the chest, may be approached quite differently than hypotension that occurs during transport of a septic patient from the SICU to the OR.

Familiarity with mechanisms and the resulting patterns of injury due to trauma is necessary to adequately diagnose and treat adverse changes in vital signs that inevitably occur during transport.

Trauma patients in the field generally benefit from a more rapid transport and less pretransport stabilization time at the scene (32,33), whereas patient transport between hospitals generally has less urgency. Patients already located at a medical center should not begin transport to another facility (interhospital transport) when in an obvious unstable condition. Intrahospital transport of unstable patients is also generally not recommended. However, patients may occasionally need emergency transport from one location to another within a hospital in order to provide therapy not available in the current setting. For example, an actively hemorrhaging patient may require transport to the OR for life-saving vascular control.

Although hemodynamically unstable patients are generally taken directly to the OR, patients with stable vital signs on admission may become unstable in the resuscitation bay or in the computed tomography (CT) scanner. In reviewing all studies that list the destination of intrahospital transport, it is noteworthy that 50% of the trauma transports are to the CT suite (13). The majority of trauma patients today undergo diagnostic CT scan on admission as part of their initial evaluation. This may explain the findings that most mishaps that happen during intrahospital transport occur in the CT area (34). The fact that transport must occasionally occur for an unstable patient is indisputable. This is occasionally necessary for a patient who needs to go to the OR (e.g., for definitive treatment of a Grade IV splenic injury), to the angiography suite (e.g., for embolization of arterial bleeding due to severe pelvic disruption), or to SICU for further resuscitation.

Hemodynamic Stability

Until recently, little was known about the effects of transportation upon cardiovascular physiology. Following the development of coronary care units (CCU) and the ability to monitor and treat patients after acute myocardial infarction, it became apparent that these patients needed to be monitored outside the CCU on telemetry units as well.

An early study showed that high-risk cardiac patients had heart rate increases simply with movement or positional changes, with potentially serious dysrhythmias temporally related to the very process of motion or change in posture (35). In this particular study, however, there were no changes in BP as a result of these dysrhythmias.

A later examination of cardiovascular responses compared patients being moved from the OR to the ICU postoperatively to a cohort of ICU patients being transported to other areas of the hospital for diagnostic or therapeutic procedures (36). All patients were followed from 30 minutes

Table 4 Factors Affecting Prehospital and Interhospital Transportation Safety and Their Relative Importance

Factor	Prehospital transport	Interhospital transport
Pretransport resuscitation and stabilization	Variable importance In combat situations, resuscitation may not commence until the patient is evacuated. In civilian practice, field stabilization is most appropriate in rural settings and in systems that provide physicians at the scene (i.e., France–German models; Volume 1, Chapter 4). In urban setting, "scoop and run" often most efficacious	Critical Once patient is at a facility that can perform lifesaving procedures, patient stability must be assured prior to transport
Early transport	Critical Most common causes of early mortality are exsanguination and neurological injury, both of which have improved outcomes with prompt treatment	Variable importance When life-threatening injuries are already treated, urgency to transport diminishes. However, patients located at a hospital with limited capabilities (e.g., the absence of neurosurgeons, CT scanner) have more urgent need to be shipped early
Patient stability	Provided as able Because of the severity of wounding, patients may be unstable. Ongoing resuscitation (during transport) is often required	Should be assured All life-threatening injuries should be treated. Monitoring and administration of cardiopulmonary support should continue at the same level as was provided at the transporting facility
Specialized transport teams	Optimal But less important than timely transport by qualified personnel	Yes Interhospital transport is rarely so urgent that specialized teams cannot be assembled
Physician accompaniment	Optimal But rarely available except in some European–civilian settings	As required If the level of care requires constant physician attention, then physician accompaniment is required

prior to, during, and for 30 minutes after transport. These investigators studied patients who were transported from the OR to the ICU, immediately following major surgery. Patients had undergone cardiac (with bypass), thoracic, or vascular procedures. There were no serious dysrhythmias during transport or episodes of significant hypotension. Increases in heart rate and BP that were significant were thought to be due to emergence from general anesthesia during the transport period and immediately thereafter. The control group of patients who were transported for studies had no significant changes in vital signs.

Two key themes emerge from a review of the data: first, patients who have the potential for cardiovascular instability can be safely transported within the hospital. Second, the presence of the appropriate personnel, monitoring, and adequate preparation prior to transfer are likely to be the key ingredients that make safe transport possible.

The ability to make therapeutic interventions at any time during the peritransport period is an important component of safety and supports the concept of an organized approach to establish a transport program.

Instability during transport can also result from alterations in ventilation, which may cause hypercarbia and hypoxia. Braman et al. (37) suggested that potentially lethal hemodynamic changes during transport resulted from blood gas abnormalities. The study followed 36 patient transports, approximately half with manual ventilation and the other half with portable volume ventilation. They found a significant incidence of hypercarbia and acidemia that led to hemodynamic complications of hypotension and cardiac dysrhythmias. Most of these changes were seen in the manual ventilation group, which prompted the recommendation of transport with a portable ventilator. A later study by Weg and Haas followed 20 ICU patients who were transported with manual ventilation. These authors demonstrated that in cases when the transport ventilator was able to approximate the same inspired FiO_2 and minute ventilation parameters during transport, which the patient was receiving prior to transport, no significant changes in hemodynamic status or blood gas measurements occurred (38).

Excessive hyperventilation during assisted ventilation should also be avoided. Aufderheide and Lurie (39) showed that hyperventilation during cardiopulmonary resuscitation decreased coronary artery perfusion and decreased survival in a pig model. The use of end-tidal CO_2 ($P_{ET}CO_2$) monitoring can minimize hyperventilation during assisted ventilation (40). Moreover, $P_{ET}CO_2$ not only reflects the alveolar ventilation, but also reflects the pulmonary circulation. Trauma patients with minimal cardiac output ($\dot{Q}$), resulting from hemorrhage, will have reduced $P_{ET}CO_2$ but increasing CO_2 in tissue ($P_{Tissue}CO_2$) and arterial blood (P_aCO_2), which can worsen traumatic brain injury (TBI) by causing increased cerebral blood flow (CBF) and intracranial pressure (ICP). Accordingly, the $P_{ET}CO_2$ is best used to gauge the level of ventilation during stable $\dot{Q}$ situations or to evaluate the adequacy of $\dot{Q}$ (and efficacy of resuscitation) in a trauma patient who is receiving stable empirically determined (based upon height and weight) minute ventilation ($\dot{V}_E$) (see Volume 2, Chapters 8 and 27) (41).

Airway and Respiratory Compromise

Establishment of a definitive airway prior to departure is of paramount importance for unstable patients.

Although patients may be transported prior to intubation, whenever patients are critically injured and unstable, they should have a definitive airway [endotracheal tube (ETT) or tracheostomy]. Volume 1, Chapter 8 discusses the basic airway management during the primary survey, and Volume 1, Chapter 9 discusses the definitive airway management for trauma.

Whether the transport is from the field, the OR, or the SICU, the presence of a secure ETT or tracheostomy tube should be verified prior to transport. Because the personnel responsible for the transport are also responsible for the maintenance of the airway during transport, these individuals must be experienced in endotracheal intubation, as well as emergent placement of a surgical airway.

Changes in respiratory compliance may occur during transport, placing the patient at risk for barotrauma or volutrauma. Noise during air transport can obscure auscultation of breath sounds. Therefore, particularly in rotary-wing transports, patients ventilated with pressure-control modes of ventilation should have a continuous reading of expiratory tidal volume displayed; a significant decrease in tidal volume should alert the clinician to a possible pneumothorax. Similarly, in the volume-control mode of mechanical ventilation, an abrupt increase in the peak inspiratory pressure may signal a tension pneumothorax, migration of the tube into the right main-stem bronchus, or an obstruction of the endotracheal tube. Most current recommendations require both exhaled volume and continuous pressure monitoring.

Profound respiratory compromise immediately following traumatic injury triggers a search for treatable mechanisms that can cause these abrupt changes. Exsanguinating hemorrhage may cause a dramatic decrease in oxygen delivery ($\dot{D}O_2$) to the tissues, resulting in total organ hypoxia. Pneumothorax or hemothorax may occur with either blunt or penetrating trauma. Pericardial tamponade is another possibility (more common acutely following penetrating trauma). Disruption of pulmonary integrity can result from several insults, including rib fractures with underlying pulmonary contusions, direct tissue destruction due to penetration of a foreign substance into the thoracic cavity, and blast effect and inhalational injury following an explosion.

Blast injury is also associated with lung injury and secondary development of air emboli, which can manifest as altered mental status or focal neurological deficits. In patients with an altered level of consciousness (e.g., TBI, substance use), aspiration is another common occurrence that necessitates endotracheal intubation. Inappropriate attention to the effects of mechanical ventilation can aggravate or exacerbate these primary insults. Protective ventilation strategies should be incorporated to minimize the possibility of ventilator-induced lung injury (VILI) (42–45).

Patients who develop the ARDS following trauma also require transport from time-to-time. These critically ill patients should not be considered "too sick to move" if they can be transferred to a location that can offer treatments that might improve outcome. Table 5 lists 39 patients with profound respiratory failure who were transported from outlying hospitals to the Shock Trauma Center at the University of Maryland as candidates for ECLS. Initiation of therapies unavailable at the referring institutions (advanced techniques of mechanical ventilation, intermittent prone positioning therapy, and continuous renal replacement therapy) allowed 23 of the patients to forego ECLS. Of those who required extra-corporeal support, 49% survived out of a predicted mortality of nearly 100%. Patients with ARDS may also require surgery, unrelated to their lung disease, and may need intrahospital transport from the ICU to the OR.

Table 5 Transport of Extremely Ill Trauma Patients

	Males ($n = 23$)	Females ($n = 16$)
Age, years (mean)	36	40
Illness/injury		
Nontrauma	20	11
Penetrating trauma	1	2
Blunt trauma	2	3
Reason for transport		
Respiratory failure	23	13
Liver failure	2	0
Shock	1	0

Source: From Ref. 55.

Continuation of mechanical ventilation with a battery-powered transport ventilator throughout transport helps to maintain mean airway pressure and oxygenation.

This is easily accomplished with portable commercially available transport ventilators with self-contained O_2 tanks and battery-supplied power for the ventilator during the transport period. An alternative to transport is to "bring the OR to the ICU" and perform the surgery at the bedside. Although this may be limited to certain procedures, successful tracheostomies, thoracotomies, and exploratory laparotomies have been increasingly performed on unstable, critically ill patients in the SICUs at many advanced trauma care centers around the world.

Intracranial Pressure Considerations

Perhaps one of the most challenging transport situations involves the patient with combined severe respiratory failure and elevated ICP. Maneuvers to minimize VILI, including decreased tidal volume and increased positive-end expiratory pressure (PEEP), may also lead to permissive hypercapnea and result in elevated ICP. If a patient is transported during the period of maximal postinjury brain edema (generally occurring on days 3–7), minor perturbations may increase ICP (46). In addition to hypercarbia-induced elevation of ICP, both hypoxemia and hypotension have been shown to correlate with poor outcome in head-injured patients and must be actively avoided during transport (47).

Extreme care should be exercised with patients who have pneumocephalus. Expansion of trapped gas inside the skull will lead to a marked increase in ICP. **Patients with basilar skull and frontal sinus fractures should be flown in a pressure-controlled cabin, as these injuries are associated with pneumocephalus.**

Prophylactic hyperventilation is now widely recognized as inappropriate for patients with elevated ICP, and efforts to assure normocarbia should be made (48).

However, a short course of hyperventilation in response to signs or symptoms of elevated ICP is appropriate, if other treatment modalities are unavailable or ineffective during transport. The best prophylaxis against acute elevations in ICP during transport is to prepare the patient and the team. The patient should be receiving sedatives and analgesics with an ICP monitor in place. Additionally, the patient should be monitored (including ICP, S_AO_2, and BP), on the transport ventilator for three to five minutes prior to transport, to ensure that the proper minute ventilation can be provided by the transport ventilator. Occasionally, these patients should receive neuromuscular blockade prior to transport as well. In addition, drugs to treat transient elevations in ICP, including sedatives (benzodiazepines and barbiturates), analgesics, hypertonic saline, and mannitol, should be readily available during transport.

Physiological Stresses of Flight

When patients are transported by fixed-wing aircraft (typically interhospital transfers) and are flying at high altitudes, an additional set of potential physiological perturbations is added. Some of these stresses also apply to rotary-wing and low-altitude fixed-wing transport, as noted subsequently. These factors must be carefully analyzed when planning a transport by air. The most prominent flight-specific complications are related to the hypobaric environment. During long-range flight in a pressurized aircraft, the cabin pressure is typically regulated to that present at an altitude between 5000 and 8000 feet. Although some aircraft that can be pressurized to an equivalent of sea level (or 1 atm) are available, if patients require evacuation in military cargo transports, actually the ambient pressures may be even lower, thereby increasing the risk of altitude-related complications.

At a cabin altitude of 8000 feet, a gas bubble will increase in volume by a factor of 1.35 compared with the volume at sea level (1 atm).

This volume expansion can cause serious consequences if the gas is trapped in a body cavity such as the thorax, cranium, eye, middle ear, paranasal sinuses, teeth, or gastrointestinal tract in the presence of an ileus. Patient-care devices are also susceptible to this effect, particularly ETT cuffs, pulmonary artery catheter balloons, pressure bags for intravenous fluids, and mechanical ventilators, all of which may require recalibration at altitude. The decreased ambient pressure also affects edema formation through a decrease in Starling forces. Patients with decreased oncotic pressure or increased vascular permeability are particularly susceptible to this phenomenon. The consequences are potentially serious in patients with impending compartment syndrome in the extremities or abdomen (see Volume 2, Chapter 34).

Another related effect of increasing altitude is a decrease in the partial pressure of oxygen with decreasing cabin ambient pressure. At a cabin altitude of 8000 feet, the barometric pressure is 565 mmHg and arterial PO_2 for normal individuals breathing room air is reduced to 55 to 60 mmHg (49). The degree of hypoxemia that patients with impaired gas exchange will experience is difficult to predict. For this reason, it is important to monitor patients at risk with pulse oximetry [and, when available, arterial blood gas (ABG) analysis], and all transported patients should receive, or have readily available, supplemental oxygen. In mechanically ventilated patients, the application of PEEP provides additional benefit for relief of hypoxemia (50).

Figure 6 Interior view of a Boeing 767 passenger jet, reconfigured for aeromedical evacuation of critically injured casualties. Note that the patient and all supporting equipment are well secured with clear access to required gear. The military transport equivalent is provided by C-130 (moderate range) and C-17 (long range) aircraft. (Figs. 10A and B and 13 A–C, respectively). *Source*: Courtesy of Maureen McCunn, Maryland, U.S.A.

In-flight patients are exposed to acceleration and deceleration forces that may be far more severe than those generally experienced during ground transport.

Litter patients in fixed-wing aircraft are typically loaded in alignment parallel to the long-axis of the aircraft. (Fig. 6) During takeoff and landing, recumbent patients are, respectively, exposed to significant acceleration and deceleration forces along the long-axis of their body, which can result in brief but significant intravascular fluid shifts and changes in intracranial pressure. A related effect is the angle of the aircraft cabin during ascent and descent, which can effectively expose the patient to unintended Trendelenburg and reverse-Trendelenburg positioning. In the absence of clear data on the best way to manage these effects, simple measures can be employed. First, communicate physiological concerns to the flight crew to determine, within the constraints of safety of flight, whether changes in the flight profile can minimize unwanted perturbations. An example would be using the entire length of the runway in order to decelerate more slowly on landing.

In the absence of axial spine injury, elevating the patient's head during periods of acceleration of the aircraft will decrease the corresponding acceleration vector along the long-axis of the patient's body and thereby minimize fluid shifts.

During both fixed- and rotary-wing evacuation, patients, medical crew, and medical equipment (such as portable O_2 tanks) have the potential to be exposed to significant turbulence. The patients at greatest risk from turbulence are those with unstable fractures, particularly spinal instability. Spinal immobilization beds have been adapted for use during air evacuation and are reliable and easy to use (Fig. 7). External fixators and traction systems with calibrated springs can be used to immobilize extremity fractures during evacuation, but traction with hanging weights cannot be used because of their susceptibility to movement in response to acceleration/deceleration and turbulence. Medical supplies and equipment (e.g., portable oxygen tanks) can become dangerous projectiles if not adequately

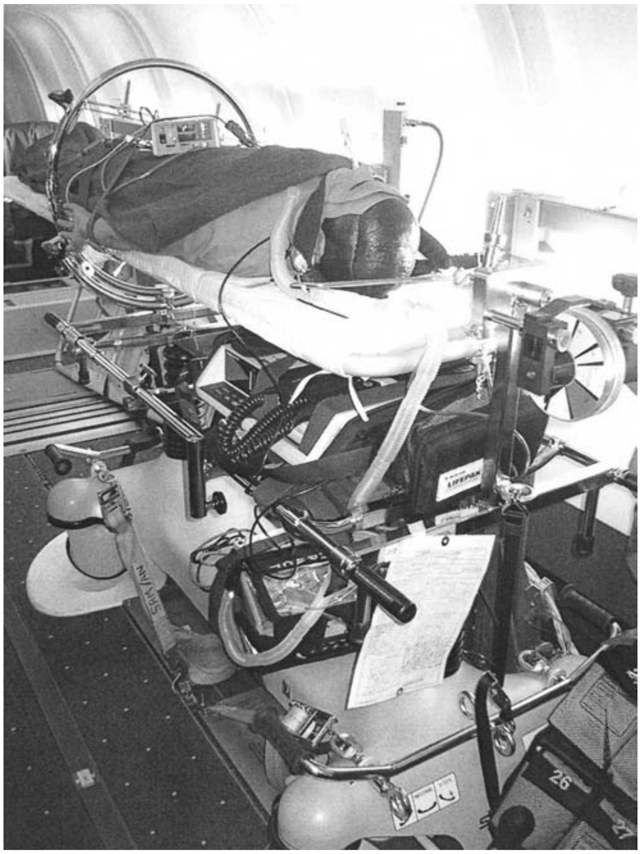

Figure 7 A standard spinal immobilization bed has been reconfigured for use inside an aircraft. This device allows a secure immobilization, inline stabilization, and the ability to rotate the patient to prone position while in flight. *Source*: Courtesy of Maureen McCunn, Maryland, U.S.A.

secured. Considerable planning is required to provide adequate security without compromising access to medical gear.

LONG-RANGE AIR TRANSPORT CONSIDERATIONS

Planning for a long-range patient transport begins with a thorough review of the stresses of flight, as they pertain to a specific patient. All critically ill patients should be transported with supplemental oxygen. It is profoundly important to ensure that adequate supplies of oxygen are available. An oxygen utilization calculation can be performed as described in Table 6. For mechanically ventilated patients, procedures must be undertaken to reduce the risk of tracheal injury and/or ETT cuff rupture from expansion of the cuff volume as altitude increases. The safest approach is to use a cuff manometer to monitor and adjust cuff pressure during changes in cabin altitude. An alternative technique is to remove air from the ETT cuff and replace it with a saline solution with sufficient pressure to eliminate leakage around the cuff. This saline cuff technique requires less in-flight monitoring, but may itself cause ischemic airway injury if cuff pressures are elevated for prolonged periods of time. Because of the low compressibility of saline compared to air, elevated pressures may be less well tolerated.

Additionally, the delivered tidal volume must be monitored periodically during flight. Modern transport ventilators have a built-in capacity to measure changes in delivered tidal volumes. For older ventilators, a Wright's spirometer should be used intermittently to assure proper volumes. Besides the normal considerations that may alter pulmonary compliance and delivered tidal volume (e.g., bronchial plugs, bronchospasm, air leakage, etc.), these patients are at higher risk for "tube migration" (i.e., right mainstem intubation), which can occur during patient transfer, and to the development of tension pneumothorax due to decrement in ambient cabin pressure (discussed subsequently) (29).

Trapped Gas

A chest X ray should be obtained prior to transport departure to rule out an occult pneumothorax.

Known or suspected trapped gas within the patient must be identified preflight. Patients with a drained pneumothorax can be transported safely as long as a functioning chest tube with an in-line Heimlich valve and pleural drainage unit is in place.

Prophylactic chest tubes for patients without evidence of hemo-pneumothorax or other extra-anatomic air are not indicated prior to air transport. Recent abdominal surgery is not a contraindication to air transport (51), but if the patient has an ileus or gastric distention, a functioning nasogastric tube must be in place and attached to intermittent suction. Obstruction of the middle ear or paranasal sinuses, can generally be managed by nasal application of a topical vasoconstrictor which often helps open the Eustacian tube (relieving pressure). Patients with trapped intra-ocular or intracranial air should not be moved by aircraft at high altitudes, unless the risk of not being evacuated (e.g., in a war zone with active shelling or hostile fire) outweighs the risk of complications from gas expansion (e.g., retinal ischemia, intracranial hypertension, and cerebral herniation). The risk of gas expansion is related to the volume of trapped gas, the altitude flown (ambient cabin pressure), the compliance of the associated tissue, and whether or not the gas has any means to vent with expansion.

Decompression Sickness/Air Embolism

Patients with decompression sickness and arterial gas embolism are at particularly high risk from exposure to reduced barometric pressure, and the benefit of transport must be weighed extremely carefully, along with the potential countermeasures available. Patients with these conditions should not be exposed to altitudes greater than (or ambient cabin pressures less than) that of the origination airfield. Patients who have been Scuba diving within 24 hours of a flight are at risk of developing decompression sickness from the lowered pressure and should not fly.

During long-range transport, it is possible to request a cabin pressure (or flight altitude) restriction on some fixed-wing models (but not all).

Flight altitude restrictions require the aircraft to fly at a lower altitude, which decreases speed and effective range and also exposes the patient to more turbulence. The U.S. Air Force has developed an inflatable, portable decompression chamber that can be used for patient transport in cargo aircraft (see Volume 2, Chapter 73).

Casts/Compartment Syndrome

Patients with recent extremity fractures are prone to edema formation, which generally worsens with altitude exposure, and can lead to compartment syndrome.

Table 6 Oxygen Utilization Calculation

Step 1	*Oxygen requirement*
	Patient oxygen usage rate
	$(FiO_2 - 0.21)/0.79 \times$ minute volume = required LPM
	Flight duration + round time = mission duration
	Required LPM $\times$ 60 = required LPH
	Mission duration $\times$ required LPH = total oxygen requirements
Step 2	*Oxygen supply*
	Compressed oxygen
	Tank pressure (psi) $\times$ tank factor # = available volume (gaseous liters)
	Liquid oxygen
	Liquid liters $\times$ 804 = available volume (gaseous liters)
Step 3	*Calculation of O_2 tank volume* (based on cylinder size and PSI)
	Evaluation of tank characteristics will determine whether supply exceeds requirement by safety factor[a]

Cylinder size	Tank factor	Volume (L) (full tank)	PSI (full tank)	Volume PSI (1/2 full)	PSI (1/2 full)
D	0.16	400	1900	200	950
E	0.28	660	1900	330	950
Q	0.94				
M	1.56	3450	2200	1725	1100
G	2.41				
H	3.14	6900	2200	3450	1100

[a]Safety factor: determine quantity of excess oxygen to carry based on specific mission parameters such as weather and likelihood of diversion. A 2-hr excess reserve per patient is a reasonable safety factor in the absence of special circumstances.
Abbreviations: LPH, liters per hour; LPM, liters per minute.

Thus, prolonged flights should be restricted in this patient population.

Extremity casts that have been in place for less than 48 to 72 hours should be modified by making bivalve cuts through the plaster or fiberglass to allow for expansion. After bivalving the cast, it should be held together with an elastic bandage to maintain limb stability.

Damage Control/Abdominal Compartment Syndrome

The same gas expansion physiology can occur in the abdomen following abdominal damage-control surgery, placing the patients at risk for abdominal compartment syndrome (ACS). The ACS can be further exacerbated by exposure to altitude and by the continued need of volume resuscitation.

When long-range transport is anticipated soon after abdominal damage control surgery, consideration should be given to leaving an open abdomen.

Burns

Burns place patients at risk for several stresses of flight including increased tissue edema, exacerbation of O_2 impairment following inhalation injuries, impaired thermoregulation, increased insensible fluid loss, and more complicated infection control (Volume 1, Chapter 34).

Strong consideration should be given to perform preflight endotracheal intubation in patients with inhalation injury. If inhalation injury is significant, intubation should be considered mandatory. Furthermore, pretransport intubation is generally recommended in borderline cases because it is difficult to monitor the airway and to perform intubation in-flight. Large-bore intravenous access must be assured, and fluid repletion begun, using one of the empiric formulas (e.g., Parkland). Monitoring with an arterial line, pulse oximetry and urine output should occur throughout the flight. **Wounds should be dressed immediately preflight and not undressed in-flight, if at all possible, to reduce the risks of contamination from the environment and to decrease evaporative losses (exacerbated by the decreased humidity of high altitude).** Heat-conserving dressings and/or active-warming devices, blankets, and sleeping bags should be used to prevent hypothermia (core temperature should be monitored in-flight).

Infection Control

Infection control is a special challenge during air evacuation due to the limited space, close physical proximity of patient and medical crew, and the limited recirculation of air. As with all patient care, standard infection control precautions should be followed, and the major challenge is carrying adequate quantities of isolation supplies and disposing of the used supplies.

When contact isolation is required for problems such as diarrhea, even more supplies must be carried. If a patient requires respiratory isolation, the decision to transport by air should be carefully weighed. If air transport is required, coordinate with the aircrew to make sure they are adequately protected. There are no studies that document the effectiveness of any particular infection control regimen in flight. Conservative practice begins with a call to the Centers for Disease Control (CDC) or following the transporting hospital's infection control guidelines for patients requiring airborne precautions. These guidelines typically recommend placing a surgical mask on the patient during transport (52). The close environment of an aircraft cabin may increase the risk of transmission further, so additional protection for the medical crew and aircrew may be warranted with masks that meet the National Institute of Occupational Safety and Health (NIOSH) standards as N95 masks.

Further protection can be facilitated by taking advantage of the airflow pattern within the aircraft cabin. This can vary from aircraft to aircraft, so coordination with the aircrew is important. For example, if air flows from front to back and from top to bottom, it is desirable to place the patient requiring airborne isolation in the aft of the aircraft, below other patients.

When patients have highly contagious airborne pathogens and must be transported with others, it is safest to intubate the patient's trachea and use filters on the inhalation and exhalation limbs of the ventilator and to minimize suctioning (or use a "closed-circuit suction device") and other maneuvers that may breech the circuit or otherwise risk jeopardizing containment during flight.

SPECIAL CIRCUMSTANCES

Disaster/Mass Casualty

Mass casualty situations are one of several transport circumstances that deserve special mention. With mass casualties, the local medical resources can be quickly overwhelmed, creating difficult decisions for resource allocation. The patients who consume the most medical resources are generally those who are the most critically ill. In a highly resource-constrained situation, the care of both these critically ill patients and those with lesser acuity will be suboptimal. When possible, the care of both sets of casualties can be improved if the most critically injured can be safely evacuated from the disaster area.

Mass casualty airlifts are most efficiently performed using a large transport aircraft that can be configured for patient evacuation (e.g., C-130 for moderate distances or C-17 for transcontinental flights; discussed subsequently) after the in-bound transport aircraft enter the disaster area. This concept is commonly employed by the U.S. Air Force, which uses both standard military MEDEVAC squadrons and CCATTs (described earlier) for manpower. The Department of Defense is one of the federal partners comprising the National Disaster Medical System, and provides the airlift capability for this civilian or military contingency system when disaster victims must be moved en masse away from a disaster site.

Contaminated Casualties

Following Sarin gas attacks in Japan, anthrax attacks in the United States, and news reports that terrorist groups possess unconventional weapons, there is now an increased recognition of the risk of terrorist attacks using chemical, biological, or radiological weapons (Volume 1, Chapter 39). Casualities produced by these events represent a potential risk to healthcare workers who care for them. Indeed, this occurred following the Sarin nerve agent terrorist attack in Matsumoto, Japan, in June 1994. This act of terrorism was not immediately recognized as a nerve agent attack. Consequently, the casualties were not decontaminated, and many members of the rescue, transport, and hospital staff became symptomatic while caring for the contaminated patients (53).

"Outgassing," the process whereby the caregiver inhales the exhaled agent from the contaminated patient, as well as volatile substances emanating from their clothing or skin, may then cause symptoms within the caregiver.

Depending on the agent used, placing contaminated casualties inside a transport vehicle can create a hazardous environment for noncontaminated patients and healthcare workers. Additionally, some substances may be difficult to decontaminate. If medical personnel become disabled and patient transport vehicles become contaminated, the medical system is less able to effectively support additional victims, and a "vicious cycle" ensues. If the patient reaches the hospital system and (depending on the agent) the building's ventilation system is contaminated, the effect can quickly spread throughout.

Accordingly, patients should be decontaminated prior to transport whenever possible. The reader is also referred to Volume 1, Chapter 4, which covers triage of contaminated patients, and Volume 1, Chapter 39, which covers the management considerations for WMDs in greater detail.

Government officials in the destination jurisdiction may not accept evacuated contaminated casualties into their area due to concerns regarding public health risks.

In "unsecured locations," such as situations of ongoing hostile fire, particularly in uncontrolled war zones, patient transport systems must prepare for the possibility that they will be asked to transport contaminated casualties. This preparation includes precoordination with government officials in the area in which they operate and in the destination to which they will be evacuating. For many types of contaminated casualties, the technical aspects of protecting personnel and the transport vehicle are complex; for others, simple isolation procedures will suffice. Thus, the nature of the containment and the recommended isolation/decontamination protocols must be known to all members of the resuscitation team (Volume 1, Chapters 4 and 39). Policies should be in place to guide transport personnel when faced with this situation. In general, the greatest good is served by delaying transport of contaminated casualties until after they have been thoroughly decontaminated.

Combat MEDEVAC and Transport

Triage decisions (Volume 1, Chapter 4) must often be modified when casualties are being transported from an "unsecured location." In a military setting, this may occur during the evacuation of casualties from a combat zone where the transport vehicle may represent a very attractive target for enemy attack. In paramilitary situations (e.g., postwar Iraq), civil unrest, looting, and lawlessness can develop, and patient transport vehicles may become targeted for theft, hijacking, or destruction. When moving multiple casualties from such an area, time can be critical for ensuring the safety of the vehicle and transport personnel.

In military firefight situations, medical care for the injured soldier begins at the scene with treatment administered by other soldiers trained in "combat lifesaving." Specialized medics are available to provide care for North Atlantic Treaty Organization (NATO) combat units. Transport of battle casualties to the next level of care by personnel without medical training is referred as casualty evacuation (CASEVAC). An example of this is the transport of a patient by a combat helicopter returning from the battlefield. A MEDEVAC occurs when patients are transported in a medically configured helicopter, by trained medical personnel (54), with varying levels of resources at the associated medical treatment facilities (MTFs).

There are five "levels of care" currently designated by NATO for the management of battle casualties. This terminology replaces the old "echelons of care" and must be understood by military commanders making triage and transport decisions on the battlefield. The NATO levels of care are not to be confused with the American College of Surgeons terminology for designation of trauma centers (Volume 1, Chapter 3), which is inversely numbered in terms of available resources. In the NATO system, the lowest level of support and treatment occurs at level I, and increases in the level of care are associated with expanded resources. Level 1 care is administered at the site of injury by other soldiers. Also included in this level are MTFs known as Battalion Aid Stations (BAS), and Shock and Trauma Platoons (STP). Surgery is not available at these level I MTFs.

Limited inpatient beds and surgical services are available at level II MTF. These include the U.S. Army Forward Surgical Team (FST) and Resuscitative Surgical System (FRSS) as shown in Volume 1, Chapter 5. Other level II MTFs include the U.S. Air Force Mobile Field Surgical Team (MFST), and the U.S. Navy Casualty Receiving Treatment Ships (CRTS). The MTFs with the widest range of resources located within a combat zone are designated as level III. These facilities have expanded diagnostic, medical, and inpatients resources. The U.S. Army's CSH has an ICU, at least six surgical operating rooms, and beds for over 200 patients (Volume 1, Chapter 5).

When moving multiple casualties from the battlefield, timing and route planning are critical for ensuring the safety of the patient, the vehicle, and transport personnel. The loss of a patient transport vehicle and medical personnel will affect numerous future patients who were dependent upon these resources.

The H-60 Blackhawk is the U.S. Army's front-line utility helicopter used for MEDEVAC missions. First deployed in 1978, the Blackhawk provides many improvements in troop and cargo lift capability compared to the UH-1 "Huey" that it replaced. The Blackhawk platform can be configured to serve a wide range of service specific roles, including the MH-60K special operations aircraft, the U.S. Air Force's HH-60G "Pavehawk," the U.S. Navy's "Seahawk" family of helicopters, the U.S. Coast Guard's HH-60J "Jayhawk" for search and rescue, and the UH-60Q MEDEVAC (described subsequently).

The UH-60Q MEDEVAC helicopter (Fig. 8) provides a six-patient litter system, onboard oxygen generation, a medical suction system, an environmental control system, cardiac monitoring systems, supplies for airway management, as well as IV supplies and solutions. The remaining monitoring and resuscitation equipment is configured by the rescue team. The helicopter has an external electrical rescue hoist and can accommodate a crew of three and up to six acute care patients. The UH-60Q is the "workhorse" aeromedical evacuation platform and has been used to save lives in Kuwait, Somalia, Afghanistan, and Iraq. The UH-60Q is used to evacuate and transport patients from hot zones to an FST or FRSS (level II facility) or to CSH levels of care.

The UH-60Q can perform all-weather terrain battlefield evacuation, combat search and rescue, hospital ship lifeline missions, deep operations support, forward surgical team transport, medical logistics resupply, medical personnel movement, and disaster/humanitarian relief. The UH-60Q will soon be supplanted by the HH-60L, which will incorporate an upgraded medical interior and electric hoist, O_2 generator, and an upgraded navigation package including a forward-looking infrared (FLIR) system, which is an infrared video camera that helps pilots navigate at night and in low-visibility situations (e.g., fog).

The CH-46 USMC is a larger helicopter (compared with the Blackhawk) used by the U.S. Marines for both assault and MEDEVAC missions (Fig. 9). The CH-46 carries a crew of four to five along with 15 casualty litters and two attendants during MEDEVAC missions. Both the Blackhawk and the CH-46 have also been used to transport civilian injured in natural disasters (e.g., December 2004 Indian Ocean tsunami and September 2005 Hurricane Katrina).

The C-130 "Hercules" (Fig. 10) is a turbo-prop, high-wing, versatile airplane predominantly used for intratheater aeromedical transport missions (e.g., from FST to CSH or from CSH to CSH). The C-130 is capable of "short takeoff landing (STOL) operations" (i.e., "STOL" from rough, dirt strips) and is the primary fixed-wing patient transport aircraft working in and out of hostile territory. The C-130 is best employed for carrying patients, troops, or equipment over medium-range distances of 75 to 750 miles (with a maximum nonrefueling range of 1500 nautical miles). The rugged "Herc" is capable of carrying a 30,000 lb payload.

The C-130 has accumulated over 20 million flight hours by the U.S. Air Force over more than three decades of use. For aeromedical evacuations, it can carry 74 litter patients and two medical attendants. However, when numerous sick patients are on board, many additional medical personnel are required.

The C-141 "Starlifter" (Fig. 11) was the first military jet aircraft designed for cargo movements over long distances with refueling capability, in the 1960s. Active duty versions of this aircraft have been retired from the U.S. Air Force or transferred to the National Guard units and thus remain in the inventory of military aircraft one may still encounter. These aircraft were part of the fleet of MEDEVAC aircraft used for patient evacuations from New Orleans following Hurricane Katrina. These aging aircraft are still used with some of the National Guard units in Iraq.

(A) (B)

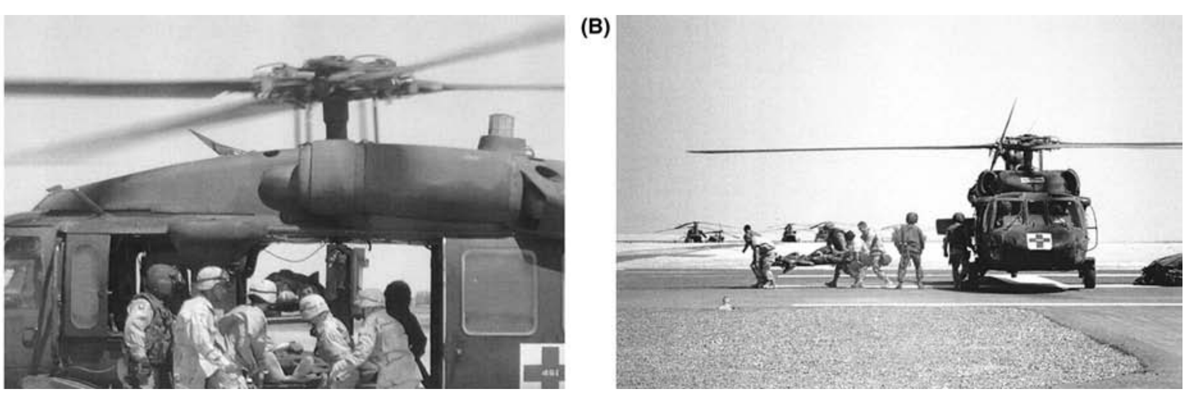

Figure 8 Blackhawk aeromedical evacuation model UH-60Q MEDEVAC. Capable of carrying six critically injured patients along with three MEDEVAC crew members. Developed for battlefield MEDEVAC, search and rescue missions, and short-range patient transport [i.e., level I medical treatment facilities (MTFs) to level II or III MTFs]. (**A**) On-loading casualties in six-litter-equipped copter. (**B**) Off-loading casualty. *Source*: Courtesy of U.S. Army.

Figure 9 CH-46 USMC helicopter. This image shows the U.S. Marines loading casualties onto the CH-46 on an unimproved airfield outside Ramadi, Iraq. The CH-46 is an all-weather, day/night, night vision goggle helicopter used by marines for MEDEVAC, assault, transport of combat troops, supplies, and equipment during amphibious and subsequent operations ashore. As a medical evacuation platform it is capable of holding 15 litters and two medical attendants in addition to the normal crew of four to five (normal crew: four—pilot, co-pilot, crew chief, and 1st mechanic; combat crew: five—pilot, co-pilot, crew chief, and two aerial gunners). Used in theatre for transport of casualties medium-range [i.e., level II medical treatment facilities to Level III or to ship (which may have level III equivalent)]. *Source*: Courtesy of Joseph F. Rappold, CDR, U.S. Navy.

The C-5 "Galaxy" (Fig. 12) is the much larger replacement for the C-141. It is one of the world's largest aircraft and can be configured for both cargo and patient transports. It can taxi on substandard runways and take off and land in relatively short distances. In 1968, it was involved in the humanitarian airlift following the devastating earthquake in Soviet Armenia. It can carry numerous tanks, fixed-wing aircraft, and helicopters with folding wings and rotor blades, respectively.

The C-17 "Globemaster III" (Fig. 13) is the newest airlift aircraft to enter the Air Force's inventory. The C-17 is a four-engine turbofan jet aircraft capable of airlifting large payloads over intercontinental ranges without refueling. Its design is intended to allow delivery of combat cargo, medical equipment, and MEDEVAC patients directly into and out of austere airfields.

The C-17 has a propulsive lift system, which uses engine exhaust to augment lift generation. By directing engine exhaust onto large flaps extended into the exhaust stream, the C-17 is capable of flying steep approaches at remarkably slow landing speeds (STOL). This equates to the aircraft's ability to land payloads as large as 160,000 pounds on runways as short as 3000 feet and as narrow as 90 feet wide.

EYE TO THE FUTURE

Although transport of critically ill patients will likely always involve trained personnel, technology will impact the level of care and the safety of transport. "Telemedicine," with high bandwidth connections between ground and aircraft, will facilitate information transfer (see Volume 2, Chapter 72). A combination of satellite and high-frequency radio connections will improve communication and transmission of data.

The U.S. National Institutes of Health (NIH) has funded a project to study the feasibility of a pneumatic-driven extracorporeal circuit, to allow field use and transport of patients with cardiovascular collapse or severe respiratory failure. Diagnostic imaging, such as FAST (focused assessment with sonography for trauma), has enhanced diagnostic procedures performed during transport (Volume 1, Chapters 8 and 27). With ever-decreasing sizes of monitors and diagnostics, transport personnel will be able to "take along" increasingly sophisticated equipment to improve transport efforts.

One important area of prehospital care is clinical research. Regional consortiums are being developed to study issues such as "best practices" in airway management and fluid resuscitation. These consortiums will be able to collect information from a large number of patients. The introduction of handheld technology has enabled EMS personnel to acquire information efficiently that can be downloaded into prehospital databases.

(A) (B)

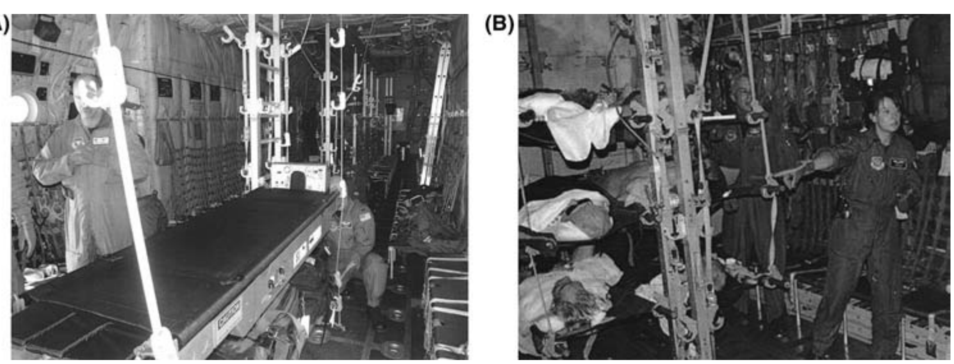

Figure 10 Interior view of C-130 Hercules. The C-130 is the predominant intratheatre aeromedical transport plane. Versions of this aircraft have been in service for over four decades and have logged over 20 million flight hours. Generally used for intermediate transport distances (75–750 miles) moving patients from Level I medical treatment facilities (MTFs) to level III MTFs or between level III MTFs. See text for description of various levels of MTF. Capable of configuring five sets of five litter stacks and an additional 25 seated passengers. (**A**) Life Support for Trauma and Transport® (LSTAT®) device is seen being secured to litter support stacks. (**B**) Patients loaded during evacuation from New Orleans following Hurricane Katrina. *Source*: Courtesy of U.S. 5th Army.

Figure 11 C-141 Starlifter. The C-141 was the first jet-powered cargo aircraft for the U.S. Air Force, starting in 1964. It has gradually been getting retired and is currently only operational in two Air National Guard units. It was the first intercontinental jet cargo aircraft that could be refueled in midair. Maximum payload is 94,500 lb, and maximum payload range is 2175 nautical miles. *Source*: Courtesy of Ref. 56.

The use of global positioning devices (GPS) is expanding. This technology allows EMS personnel to find locations more rapidly. Motor vehicles with Automatic Crash Notification (CAN) technologies use sensors, GPS, and wireless communication to notify locations of crashes. This will decrease the response time by EMS.

A continuing problem in transport of the trauma patient from the level II (FST or FRSS) or III (CSH) to level IV or V facilities is relay of information regarding the patients' operative findings and the details of surgical repair. The current solution is to write down the injuries directly upon the patient's bandages (Fig. 14A and B). However, if midtransport instability requires the take down of dressings, or if they become soiled, the writing may become lost or illegible. Accordingly, improved systems need to be developed to document this information and send it with the patient. Some physicians are taking digital pictures and sending the images on CDs or flash memory sticks with the patients. Others are dictating the

Figure 12 C-5 Galaxy. The largest cargo aircraft in the U.S. inventory, it can carry a payload of 260,000 lb and has a fully loaded range of 2160 nautical miles. It is refuelable in the air. Original model became operational in 1970. The C-5 is being upgraded to continue service to a projected date of 2040. *Source*: Courtesy of Ref. 57.

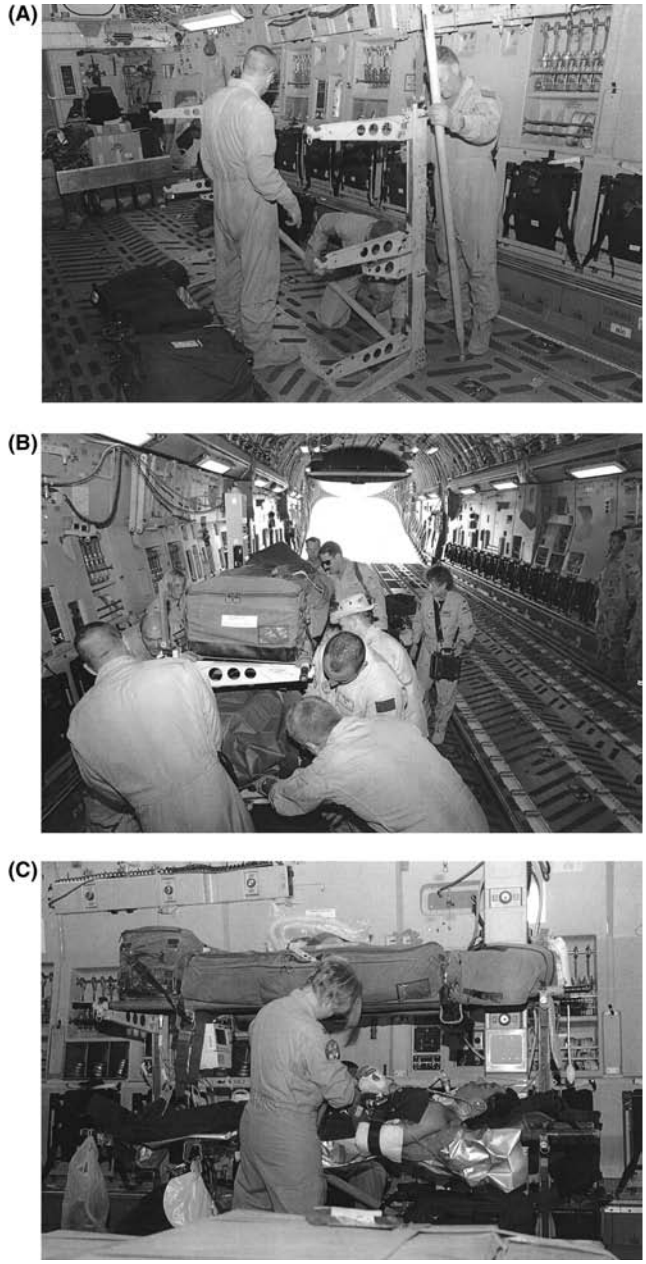

Figure 13 C-17 Turbofan MEDEVAC aircraft. The newest and most advanced long-range MEDEVAC platform in use. Generally employed for intercontinental flights, including transport of wounded soldiers from Afghanistan or Iraq to Germany, i.e., between levels III and IV medical treatment facilities (MTFs). See text for description of various levels of MTF. The C-17 has a maximum payload of 160,000 lb and a nonrefueling flight range of 5000 nautical miles. (**A**) Crewmen set up litter support structures. (**B**) Patient (*middle* stretcher) and equipment (*top* stretcher) are loaded through rear door (still open) by the Critical Care Air Transport Team (CCATT) members. (**C**) Side view of patient [previously being loaded in (**B**)] on middle stretcher attended to by member of the CCATT. Tracheotomized patient receives positive pressure ventilation, as well as infused drugs and invasive monitoring during flight. *Source*: Courtesy of José A. Acosta, South Eastern Afghanistan, 2005.

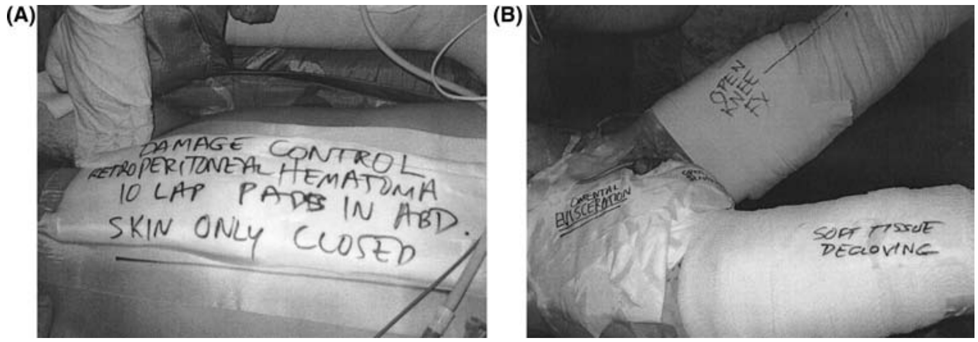

Figure 14 Notes written upon patient bandages to communicate injuries, surgical repairs, etc., to next level of care. (**A**) Abdominal dressing "damage control, retroperitoneal hematoma, 10 lap pads in abd., skin only closed" [orientation of patient: head to the *right* (not shown) groin on *left*], crewman's hand shown palpating right femoral pulse. (**B**) Orthopedic wounds "open (*left*) knee F_x, soft tissue degloving (*right*)," omental evisceration, and open scrotal injuries. *Source*: Courtesy of Joseph F. Rappold, CDR, U.S. Navy.

operative reports and sending this digitally or as a dictaphone tape. We need to advance and standardize this important patient communication, utilizing this previously mentioned technology, so that it is uniformly utilized to increase the quality of care our patients receive after being wounded. Improved outcomes feedback to the resuscitating and operating teams in the field is also of great need.

Pain management during transport is improving, as the U.S. Air Force CCATTs provide sedatives and analgesics in flight. In addition, there is an increasing use of continuous regional infusion devices and patient-controlled analgesia (PCA) for those patients who can self-administer analgesics (58). Further incorporation of in-hospital therapies and monitoring modalities needs to be integrated into transport care.

SUMMARY

Short distance intrahospital transport (e.g., the OR to the ICU) and long-range ground or air transport can be accomplished safely with the most critically ill or injured patients. Patients who have the potential for cardiovascular or respiratory instability can be safely transported as long as the appropriate personnel, equipment, and monitoring are provided, and thorough preparation occurs. One key principle lies in assuming that changes in the patient's status will occur and being prepared for these changes. Anticipating any possible alterations and devising diagnostic and therapeutic plans that can be instituted en route should be routine practice for transport teams. An experienced transport team should be available at all institutions engaged in these activities and ongoing competency training should be maintained.

Familiarity with mechanisms and patterns of injury occurring during trauma (Volume 1, Chapter 2) is necessary to adequately diagnose and treat adverse changes in vital signs seen during transport. In mass casualty disaster or combat situations, patient transport systems must be capable of transporting contaminated casualties.

In hostile combat conditions, numerous triage transport decisions need to be made and amended as conditions change. Occasionally, the best decision is to load the least critical patients first because many of them can be loaded quickly and they are most likely to survive their injury or illness. Then, if the vehicle is forced to leave prior to being fully loaded, the greatest good will have been served. In contrast, in peacetime and during war when the triage assembly area is protected from hostile fire, the sickest patients are loaded and evacuated first because the less ill patients can safely wait for the next transport.

Finally, technology and telemedicine (Volume 2, Chapter 72) will continue to develop new modalities and capabilities that enhance the ability and the safety of transport. All physicians caring for trauma patients should be cognizant of these new discoveries and continuously re-train for multicasualty situations.

KEY POINTS

- The level of care during transport should be equal to or exceed the level of care the patient is receiving prior to departure.
- Patients should be moved from one area of care to another only if the expected benefit of the transport (diagnostic procedure or operative management) exceeds the transport risk.
- The transport personnel must assume that perturbations in the patient's status will occur and be prepared for these changes.
- Ground ambulances can be configured to closely duplicate the capabilities found in the trauma bay and in the SICU.
- Civilian interhospital transfers and prehospital transport in urban areas have not been shown to benefit from helicopter transport (14,15).
- Fixed-wing aircraft are most beneficial when transporting patients over long distances (usually >300 miles for large planes), as may be required when the patient is located in a remote area, or when highly specialized care is required for a rural-based patient.
- The transport team leader should be trained to manage patients of all ages and be prepared to deal with a multitude of acute trauma and medical conditions. Additional team members should also be experienced in the transport of critically injured patients.
- In all cases, standards during transport must match the minimum care provided prior to transport.
- In elective settings, "early transport" means to do so before secondary problems occur (e.g., infection, sepsis, and acute respiratory distress syndrome), which make transport more dangerous.
- Anticipating complications and devising diagnostic and treatment plans to remedy life-threatening

conditions en route should be routine practice for transport teams.

- Familiarity with mechanisms and the resulting patterns of injury due to trauma is necessary to adequately diagnose and treat adverse changes in vital signs that inevitably occur during transport.
- The ability to make therapeutic interventions at any time during the peritransport period is an important component of safety and supports the concept of an organized approach to establish a transport program.
- Establishment of a definitive airway prior to departure is of paramount importance for unstable patients.
- Continuation of mechanical ventilation with a battery-powered transport ventilator throughout transport helps to maintain mean airway pressure and oxygenation.
- Patients with basilar skull and frontal sinus fractures should be flown in a pressure-controlled cabin, as these injuries are associated with pneumocephalus.
- At a cabin altitude of 8000 feet, a gas bubble will increase in volume by a factor of 1.35 compared with the volume at sea level (1 atm).
- In-flight patients are exposed to acceleration and deceleration forces that may be far more severe than those generally experienced during ground transport.
- In the absence of axial spine injury, elevating the patient's head during periods of acceleration of the aircraft will decrease the corresponding acceleration vector along the long-axis of the patient's body and thereby minimize fluid shifts.
- Planning for a long-range patient transport begins with a thorough review of the stresses of flight, as they pertain to a specific patient.
- A chest X-ray should be obtained prior to transport departure to rule out an occult pneumothorax.
- During long-range transport, it is possible to request a cabin pressure (or flight altitude) restriction on some fixed-wing models (but not all).
- Patients with recent extremity fractures are prone to edema formation, which generally worsens with altitude exposure, and can lead to compartment syndrome.
- When long-range transport is anticipated soon after abdominal damage control surgery, consideration should be given to leaving an open abdomen.
- Wounds should be dressed immediately preflight and not undressed in-flight, if at all possible, to reduce the risk of contamination from the environment and to decrease evaporative losses (exacerbated by the decreased humidity of high altitude).
- When patients have highly contagious airborne pathogens and must be transported with others, it is safest to intubate the patient's trachea and use filters on the inhalation and exhalation limbs of the ventilator and to minimize suctioning (or use a "closed-circuit suction device") and other maneuvers that may breech the circuit or otherwise risk jeopardizing containment during flight.
- "Outgassing," the process whereby the caregiver inhales the exhaled agent from the contaminated patient, as well as volatile substances emanating from their clothing or skin, may then cause symptoms within the caregiver.
- Government officials in the destination jurisdiction may not accept evacuated contaminated casualties into their area due to concerns regarding public health risks.
- In "unsecured locations," such as situations of ongoing hostile fire, particularly in uncontrolled war zones, patient transport systems must prepare for the possibility that they will be asked to transport contaminated casualties.

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8

Primary Survey: Initial Resuscitation Priorities

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INTRODUCTION

Optimum treatment of severely injured trauma victims requires a rapid and organized assessment and treatment system. The American College of Surgeons (ACS) has developed a graded approach involving primary and secondary surveys for injuries, using a system of management described as Advanced Trauma Life Support® (ATLS®). The "primary survey" (PS) is the initial phase of management reviewed in this chapter. During the PS, life-threatening conditions are rapidly identified and life-saving treatment is expeditiously initiated. Resuscitation efforts occur coincident with the PS and continue throughout the next phase of care. Optimally, the PS is completed in the first three to five minutes. However, when multiple life-threatening injuries are encountered, the PS takes longer to complete.

Once the PS is completed, the "secondary survey" (SS) commences whereupon all other injuries (not immediately posing a threat to life) are identified and staged using more thorough evaluation tools (Volume 1, Chapter 14). Some have recommended that a "tertiary survey" (Volume 1, Chapter 42) be undertaken in the surgical intensive care unit (SICU) or in the ward after the patient returns from the operating room (OR) or from the resuscitation suite and is characterized as a complete systematic review of the patientincluding evaluation of all prior studies in an effort to ensure that all known and potential injuries have been fully staged. The more severe the injuries are at presentation, the greater the likelihood that injuries will be missed during the PS and SS. Conversely, the more rigorous the application of the PS and SS, the less likely that missed injuries will occur.

The PS is performed in a prescribed sequence which reviews the most life-threatening conditions first including evaluation of airway, breathing, circulation, disability, and exposure (ABCDEs) (Table 1). This chapter reviews each evaluation and treatment step in the process. The PS management priorities are similar for children (Volume 1, Chapter 36), the elderly (Volume 1, Chapter 37), and pregnant patients ((Volume 1, Chapter 38).

AIRWAY MAINTENANCE WITH CERVICAL SPINE PROTECTION

The PS of the trauma patient begins with assessment and management of the airway. Common factors contributing to airway compromise include relaxation of the tongue and oropharynx during unconsciousness. Airway management is further complicated following trauma to the face, head, neck, or chest and by the presence of bleeding, vomitus, and other foreign objects in the airway (e.g., broken teeth).

The airway examination begins by evaluating patency and adequacy of ventilation. The special "proviso" in the ATLS paradigm is that the cervical spine should be protected (i.e., maintained in-line and immobilized) in all cases deemed relevant (based upon considerations such as "mechanism of injury") while airway management is instituted.

Assessment

Assessment of airway patency and spontaneous breathing is the crucial first step, which should be completed within the initial 10 to 15 seconds of the PS. Look, listen, and feel for diminished or absent air movement (Table 2). If the patient has an appropriate verbal response to questioning, this indicates a patent airway. However, ability to phonate does not necessarily indicate that the airway is "safe," "normal," or "optimal." Ability to phonate only indicates that the airway is unlikely to be in immediate jeopardy and that ventilation is occurring. If apnea is present, the rescuer should proceed to manual airway maneuvers with assisted bag-valve-mask (BVM) ventilation using 100% O_2 while preparing to establish a definitive airway (Volume 1, Chapter 9).

A partially obstructed airway presents with noisy breathing (stridor) and tachypnea. The tongue is the principal source of oropharyngeal obstruction in unresponsive

Table 1 Primary Survey Overview

Step	System	Description
A	Airway maintenance (with C-spine protection)	Ensure patency of the airway with in-line C-spine immobilization, application of oxygen
B	Breathing	Verify breathing and address life-threatening conditions
C	Circulation (with hemorrhage control)	Check for external and internal bleeding, heart rate, pulse character, blood pressure, and capillary refill
D	Disability (neurological evaluation)	Evaluate neurological status (GCS and pupils)
E	Exposure (with environmental control)	Completely undress the patient, examine the entire surface searching for injuries, especially examine the axillae, inguinal, and rectal area, logroll patient to examine the back, cover victim to avoid hypothermia

Abbreviations: C-spine, cervical spine; GCS, Glasgow Coma Scale.

patients; however, neck trauma can result in laryngeal fractures and hematomas which can result in partial airway obstruction and stridor (Table 3). Other signs of laryngeal trauma include hoarseness, aphonation, or hypersalivation. Patients with facial trauma may adopt unusual postures to aid airway maintenance, such as sitting upright and leaning forward, as when bi-mandibular fractures are present. This airway supportive posture is impossible to maintain by the supine patient strapped to a backboard. Accordingly, these patients may be transported to the hospital in the sitting position. Whenever airway injury or stridor (suggesting partial airway obstruction) is encountered, airway management emphasizes maintenance of spontaneous ventilation during prompt establishment of a definitive airway. Often use of a fiberoptic bronchoscope (FOB) is the optimum technique in such situations (Volume 1, Chapter 9). Physicians with sufficient experience (and the tools) necessary to perform a surgical airway should also be present during these manipulations.

Table 2 Steps in Assessment of Airway Patency

Assessment step	Description
1	Observe presence or absence of "fogging" on O_2 mask (may not be detectable in warm, dry environments)
2	Listen for breath sounds and feel for exhaled breath on examiner's ear to determine whether apnea is present; verbalization is a sign of airway patency
3	Observe the chest expansion and any sign of respiratory distress, nasal flaring, substernal, supraclavicular, or intercostal retractions of foreign bodies, and signs of airway injuries
4	Look for blood, vomitus, bone fragments, broken teeth, dentures, and other foreign bodies
5	Listen for stridor or noisy breathing

Table 3 Sources of Airway Obstruction Following Trauma

Obstruction source	Description and comments
Tongue	Most common source of obstruction is tongue and relaxation of oropharynx in an unconscious patient
Supraglottic tissues	In obese patients, soft tissue adiposity and redundant tissue can obstruct the airway in the hypopharynx and/or supraglottic region
Edema	Patients who normally sleep without snoring or airway obstruction may develop obstruction secondary to edema, especially following burns and/or massive resuscitation
Hematoma	Both penetrating and blunt trauma to the neck can lead to hematoma formation which can expand and obstruct the airway
Maxillo-facial trauma	Mandibular fractures can cause partial or complete airway obstruction, which can cause stridor. This can also lead to difficult mask ventilation
Laryngeal fracture	Blunt trauma to neck (e.g., "clothesline" injury) can cause laryngeal fractures and partial or complete airway obstruction
Laryngo-tracheal separation	Blunt or penetrating injury to the neck can also cause partial or complete larygno-tracheal separation. Maintain spontaneous ventilation and intubate awake usually with FOB (see Volume 1, Chapter 9).
Blood and vomitus	Aspiration of a large quantity of blood or vomit can completely obstruct airways leading to desaturation. Small volume aspiration of low pH vomit can cause a chemical burn and severe ARDS. Use FOB to clear airways
Avulsed teeth and other foreign bodies	Following maxillo-facial trauma, teeth are often broken and may be aspirated. Be aware, examine patient and chest X rays, remove lost teeth or other FBs from the airway with FOB

Abbreviations: ARDS, acute respiratory distress syndrome; FB, foreign body; FOB, fiberoptic bronchoscope.

Basic Airway Management

Supplemental Oxygen and Chin-Lift/Jaw-Thrust Maneuvers

Cervical spine immobilization should be maintained until neck injuries are ruled out. Airway opening techniques that do not impose neck movement, such as the chin-lift or jaw-thrust maneuvers can usually alleviate a partially obstructed airway (Table 4). The head-tilt maneuver (requiring atlanto-occipital extension) is not utilized in blunt trauma patients because a cervical spinal cord injury (SCI) can be generated or exacerbated in the setting of unstable cervical skeletal or ligamentous injuries. When BVM ventilation is indicated, normally one hand secures the mask to the face while the other hand ventilates by

Table 4 Basic Airway Management Maneuvers in the Trauma Patient

Administration of supplemental oxygen, 100% oxygen by high-flow mask
Airway positioning by the chin lift and jaw thrust (avoid head-tilt)
Removal of blood or foreign bodies by suctioning with gentle techniques
Use of oropharyngeal or nasopharyngeal airways

squeezing. However, when BVM ventilation is difficult, a two-person BVM ventilation technique is indicated (Volume 1, Chapter 9). The two-handed method facilitates a better "seal" than the single-handed technique. In either case, cricoid pressure should be maintained whenever actively ventilating a trauma patient by mask (i.e., with positive pressure). When airway obstruction is caused by mandibular fractures, manual anterior distraction of the flail anterior mandibular segment can provide temporary return of airway patency as a temporizing maneuver prior to, or during, establishment of a definitive airway (via FOB or surgical airway). Often these patients will not tolerate the supine position (due to immediate positional airway obstruction) until the airway is secured with an endotracheal tube (ETT). Supplemental oxygen should be administered to all trauma patients with a device providing a high oxygen concentration and a high flow rate (Table 5). Gentle pharyngeal suction and removal of blood or foreign bodies also helps maintain airway patency.

Oropharyngeal and Nasopharyngeal Airways

Properly sized oropharyngeal or nasopharyngeal airways may be useful. An oropharyngeal airway can temporarily be used in unconscious patients with diminished airway reflexes. This device can trigger gagging, coughing, and emesis in awake patients and laryngospasm in partially anesthetized or drug-intoxicated patients.

Nasopharyngeal airways are optimal for maintenance of airway patency in semiconscious or unconscious patients. This device is less likely to stimulate gagging and vomiting than an oropharyngeal airway and is especially useful in patients with clenched teeth, and those who are unable or unwilling to open their mouths. However, nasopharyngeal airways can initiate nasal bleeding and should not be used in patients with a known or suspected basilar skull fracture or cribiform plate injury. Skull base fractures and/or massive facial injuries can be associated with cribriform plate fractures, and blind insertion of tubes through the nares under these conditions has resulted in passage into the cranial vault. Nasopharyngeal airways can also become clogged by mucous, blood, or vomit. If this occurs, the airway should be suctioned to restore patency. Finally, careful consideration should be used when employing the nasopharyngeal airway in cases of potential coagulopathy.

Table 5 Estimated Delivery of Oxygen Concentration of Commonly Employed Delivery Devices

O_2 delivery device	O_2 flow rate (L/min)	FiO_2
Nasal cannulae	2	0.21–0.24
	4	0.26
	10	0.30–0.46
Simple mask	6	0.35
	10	0.55
Partial rebreather mask	10	0.6
Nonrebreather mask	10	0.8–0.95

Aspiration Precautions and Suction Devices

Trauma patients are at increased risk of regurgitation and subsequent aspiration. The risk of aspiration pneumonitis is further elevated with increasing acidity and volume of gastric contents and when particulate matter is aspirated. Therefore, aspiration precautions must always be considered.

Cricoid pressure (also known as "Sellick maneuver" or crico-esophageal pressure) denotes downward (posterior) digital pressure on the anterior neck overlying the cricoid cartilage. The downward (posterior) movement of the cricoid ring (complete in adults) will physically occlude the esophagus and decrease the risk of gastric regurgitation; simultaneously it also reduces the risk of gastric distention during BVM ventilation.

Cricoid pressure should be maintained until the tracheal tube cuff is inflated and correct positioning of the ETT is confirmed. Cricoid pressure should not be applied in patients suffering from laryngeal or tracheal injuries because this maneuver can result in complete crico-tracheal separation. Similarly, cricoid pressure is best removed in favor of oropharyngeal suctioning during active vomiting because maintaining cricoid pressure in this setting imposes the risk of esophageal rupture. When vomiting occurs during assessment or securement of the airway in a supine patient strapped to a backboard, the patient should be tilted head-down with a 30° lateral tilt to prevent aspiration. Suction devices should always be ready during airway interventions. The airway is cleared under direct vision using a large-volume suction device (tonsil suction tip or the Yankauer sucker). Caution must be taken to avoid inducing or exacerbating oropharyngeal bleeding when using any suction device. A long, soft flexible suction catheter is useful for clearing secretions from nasopharyngeal airways and the ETT.

Cervical Spine Precautions

Serious cervical spine injuries occur in 1% to 3% of severe trauma patients (1,2). Furthermore, in blunt trauma patients requiring emergent tracheal intubation, many cervical spine injuries are potentially unstable (Fig. 1) (3). Therefore, all blunt trauma patients should be suspected of having an unstable cervical spine injury until proven otherwise. Devices used to immobilize the cervical spine include rigid cervical spine collars, sand bags, and taping the head to rigid backboards. One should not be over-reliant on any single device (Table 6). For example, a rigid cervical collar alone provides limited immobilization of the cervical spine (4). Co-employment of a rigid cervical collar and a backboard with sand bags taped on both sides of the head provides better immobilization than the collar alone (5). However, these cervical spine protective devices can complicate airway management, especially when the need for a definitive airway occurs abruptly or unexpectedly.

Manual in-line immobilization of the cervical spine is easy and effective if applied appropriately. After induction and prior to laryngoscopy, the rigid cervical collar is removed to facilitate intubation because these devices make airway management difficult (6,7). Cervical traction

Figure 1 Cervical spine injuries sustained during a fall from a height. Note abnormal anterior angulation at C5–C6.

Table 7 Indications for Definitive Airway

Indication	Clinical example(s)
Need for airway protection	Unconsciousness (e.g., GCS ≤ 8, drug or alcohol intoxication, metabolic coma)
	Severe maxillofacial fractures
	Risk of aspiration (e.g., bleeding, vomiting)
	Risk of airway obstruction (e.g., expanding neck hematoma, laryngeal or tracheal injury, massive burns, or fluid resuscitation, stridor of any etiology)
Need for ventilation	Apnea (e.g., unconsciousness, neuromuscular paralysis)
	Inadequate respiratory effort (e.g., opiate overdose, respiratory muscle fatigue, hypercarbia, severe metabolic acidosis, tension pneumothorax, flail chest, hemothorax, COPD)
	Severe TBI (GCS ≤ 8) with temporary need for hyperventilation
Need for oxygenation	Hypoxia or cyanosis
	Carbon monoxide toxicity
	Respiratory failure, ARDS
	Tension pneumothorax
Anticipated need for optimum resuscitation	Exsanguination (hypovolemic shock)
	Septic shock
	Neurogenic or cardiogenic shock

Abbreviations: ARDS, acute respiratory distress syndrome; COPD, chronic obstructive pulmonary disease; GCS, Glasgow Coma Scale; TBI, traumatic brain injury.

or distraction per se is no longer recommended; however, the patient should be prevented from flexing, extending, or rotating the neck. Occasionally, absolute immobilization of the neck may be overridden by the requirement for providing an adequate airway in hypoxemic patients. However, even under these circumstances, the cervical movement should be limited to the minimum required to achieve patency. Newer airway management devices (Volume 1, Chapter 9) may allow for rapid intubation with less cervical motion than conventional direct laryngoscopy.

Definitive Airway Management

The presence of a cuffed tube in the trachea is the best way to ensure delivery of a high concentration of oxygen and effective ventilation following trauma. Cuffed tubes also protect the lungs from aspiration and facilitate the suctioning of aspirated blood and airway secretions. Indications for tracheal intubation in trauma patients include protection of the airway, securing effective oxygenation and ventilation, and the anticipation of ongoing resuscitation (Table 7). Definitive airway management is fully reviewed in Volume 1, Chapter 9.

Direct laryngoscopy with orotracheal intubation is the principal method used in acute trauma patients because of speed and technical advantages. Blind nasal techniques are contraindicated in cases with suspected basilar skull fracture or partial airway obstruction (i.e., stridor). However, FOB can facilitate nasal (or oral) intubation in stable, cooperative patients with difficult airways or known cervical spine injuries. The urgency for airway intervention most often dictates the plan. Definitive airway management should always be preceded by pre-oxygenation. **Assisted ventilation (i.e., "modified RSI") is frequently justified because trauma patients are often hypoxemic and hypercapneic.**

Rapid Sequence Induction

All patients should receive 100% oxygen by the facemask or via the BVM ventilation device for a full five minutes or with four to eight vital capacity breaths prior to initiating RSI. Suction devices should be ready to use at any time. RSI intubation is accompanied by cricoid pressure, manual in-line cervical immobilization (Fig. 2), administration of an induction agent (typically etomidate), and a neuromuscular blocking (NMB) drug (e.g., succinylcholine or rocuronium) to facilitate intubation. Re-adjustment of the cricoid pressure ("laryngeal manipulation") to allow a better view, and use of a rigid stylette typically improve intubation success in difficult-to-intubate patients (8,9). During

Table 6 Cervical Spine Stabilization Devices and Respective Limitations

Immobilization device	Quality of cervical immobilization	Limitations and comments
Halo with Minerva jacket	Excellent	Not practical in resuscitation situation
Rigid cervical collars (e.g., Philadelphia collar)	Suboptimal	Inadequate immobilization in flexion–extension motion
Soft neck collars	Ineffective	Not intended for use in spinal immobilization
Sandbags or blocks taped to side of head	Effective, if taped properly	Risk of weight-induced injury, if not taped properly, particularly when airway protection requires turning the patient onto the side

Figure 2 Manual in-line cervical immobilization with cricoid pressure during intubation attempt. In this figure, the cervical stabilization is being performed with the right hand of an assistant. Normally, the assistant will be standing on the intubator's left side (behind the patient) and uses two hands to provide in-line stabilization (as shown in Volume 1, Chapter 9, Fig. 7).

intubation attempts, the patient's oxygen saturation, heart rate (HR), and blood pressure (BP) should be carefully monitored. Intubation attempts should be interrupted and the patient must be re-oxygenated using BVM ventilation if the procedure takes more than 30 seconds or whenever desaturation ($S_aO_2 < 90\%$) occurs. If intubation attempts fail and adequate oxygenation and gas exchange cannot be achieved using standard BVM ventilation techniques, a laryngeal mask airway (LMA) should be considered as per the American Society of Anesthesiologists (ASA) Difficult Airway algorithm (Volume 1, Chapter 9). If oxygenation is maintained with BVM ventilation, numerous nonsurgical intubation methods can be employed; when unsuccessful, a surgical airway should be achieved.

Following intubation, the tube position must be confirmed with measurement of end-tidal CO_2 ($P_{ET}CO_2$) or by use of an esophageal detector device (EDD) in conjunction with clinical signs. If any doubt regarding the ETT position remains, a second visualization with the laryngoscope should be performed to confirm the presence of the tube passing between the cords or the FOB should be employed to confirm that the tube is positioned within the trachea (verified by visualization of the tracheal rings and the carina as the FOB exits the end of the ETT).

Once the tube is confirmed to be within the trachea, the insertion depth should be established by "balloting" the balloon in the suprasternal notch and documenting the centimeter markings on the ETT at the upper incisions (normal 70 kg males approximate 23 cm, females ~21 cm). Next, the tube must be tightly secured in place at that position with tape or sutures and monitoring with pulse oxymetry and $P_{ET}CO_2$ should be continued. A chest radiograph (CXR) should be obtained to further confirm (and chronicle) ETT position.

Alternative Emergency Airway Devices

Inability to ventilate by BVM or intubate constitutes a crisis situation. Airway adjuncts, such as the LMA and esophageal-tracheal combitube (ETC), are useful backup options to facilitate gas exchange in these difficult airway situations (10–17). These airway adjuncts are also used to provide a temporary airway in some communities or countries where emergency medical service (EMS) providers are not permitted or trained to perform endotracheal intubation. Prior to insertion of these devices, blood, secretions, and any foreign bodies should be removed. Also, note that both of these emergency airway aids (LMA and ETC) are supraglottic solutions. If the airway is obstructed at the level of the glottis or just below, these devices will not be effective and a "surgical airway" is required. Both of these devices are "blindly" inserted as well and relatively contraindicated if there is a known or suspected supraglottic abscess or hematoma that is likely to rupture during insertion.

Surgical Airway

In the event that endotracheal intubation is deemed to be impossible, a "surgical airway" should be considered. If mask ventilation is possible, or subsequent employment of the LMA or ETC makes gas exchange possible, the patient can then be temporarily ventilated using these devices while the "surgical airway" is being performed. If ventilation is not possible despite the use of the preceeding (or other) emergency airway techniques, a surgical airway should be immediately performed. Three procedures qualify as surgical airway options in the emergency setting: percutaneous needle cricothyroidotomy, surgical cricothyroidotomy, and emergency tracheostomy (subsequently discussed in Volume 1, Chapter 9).

Percutaneous needle cricothyroidotomy is simple and effective but only a temporary method that should be replaced by surgical cricothyroidotomy/tracheostomy or used as a bridge while other definitive techniques are employed (e.g., FOB, retrograde, etc.). It is not possible to ventilate a patient through a needle cricothyroidectomy using standard BVM ventilation devices. It is possible to oxygenate using oxygen insufflation in a spontaneously ventilating patient. However, this technique does not provide adequate ventilation; consequently, the P_aCO_2 will rise. Accordingly, needle cricothyroidotomy requires that transtracheal jet ventilation (TTJV) at 25 to 50 PSI be used to facilliatate ventilation (Volume 1, Chapter 9).

Surgical cricothyroidotomy is usually preferred to tracheostomy because it is easier and quicker to perform and is associated with a lower incidence of bleeding complications. Surgical cricothyroidotomy is not indicated for children less than 12 years of age because the cricoid cartilage is the narrowest part and the only circumferential support to the upper trachea. Other contraindications for a cricothyroidotomy include patients with laryngeal fractures or abnormalities (e.g., neoplasms and inflammatory states).

Confirmation of Tracheal Intubation

Unintentional esophageal intubation is a common complication in the emergency setting, and the consequences are catastrophic if not immediately recognized (18). Thus, confirmation of endotracheal intubation must occur in all patients (19,20). The various methods for confirming ETT position are divided into two main categories: direct (failsafe) and indirect (nonfailsafe).

Failsafe methods include the three common ways to directly confirm ETT position: (*i*) the trachea is cut in the neck and the tube is inserted under direct vision; (*ii*) the ETT is placed translaryngeally and the laryngoscopist can easily verify the position because of a Mallampatti grade 1 view (seeing the ETT through the cords); and (*iii*) an FOB is passed through the ETT and tracheal rings are observed.

Nonfailsafe (indirect) methods include (*i*) clinical signs such as bilateral breath sounds (these are fraught with error) and (*ii*) $P_{ET}CO_2$ and use of the EDD (21–23). Unfortunately, the failsafe methods are not always available (or practical) in the emergency trauma setting. In some trauma patients, a grade III or IV laryngeal view does not allow direct visual verification of the ETT within the cords, and an FOB may not be immediately available. Accordingly, all trauma patients must have $P_{ET}CO_2$ detected following intubation. In situations when no cardiac output is expected [e.g., full arrest with inadequate cardiopulmonary resuscitation (CPR)], an EDD is most predictive. Additional confirmatory clinical signs of ETT position are helpful, but are less reliable than $P_{ET}CO_2$ and the EDD. The detection of $P_{ET}CO_2$ is a very accurate means of detecting ETT placement in noncardiac arrest situations (21). However, this method is less accurate when CPR is in progress (22,24,25). The inaccuracy is due to reduced pulmonary blood flow, one of the most prominent physiological characteristics during CPR. The CXR or fluoroscope can also be used to help confirm ETT position, but the detection of $P_{ET}CO_2$ is generally quicker to obtain.

The EDD method confirms tracheal intubation by the aspiration of air from the tracheal end of the tube (23). Two types of EDD are available, a syringe type and a self-inflating bulb (SIB). Both types can occasionally give false results, which may occur in the presence of vomitus, blood, or particulate matter in the airway, bronchospasm, endobronchial intubation, the ETT having its bevel against the tracheal wall, or reduced functional residual capacity (FRC) (22).

Clinical signs are the most error prone and are always of secondary importance (24). Clinical signs include auscultation of the chest, epigastrium, observation of symmetric chest rise, "fogging" (condensation) of the ETT, and so on. Auscultation of bilateral breath sounds should always be performed following intubation, but this clinical finding should not be used as the "definitive" endpoint confirming intubation (24,25). Rather, auscultation is used best to evaluate the adequacy and bilaterality of air movement within the lungs after intubation has already been confirmed using $P_{ET}CO_2$ or EDD. Additionally, documenting the presence of bilateral breath sounds and auscultation over the epigastrium should follow the insertion of gastric suction or feeding tubes as an initial source of confirming position. The CXR should be reviewed prior to administering tube feeds or contrast through tubes thought to be in the stomach.

BREATHING ASSESSMENT AND MAINTENANCE

The "B" of the ABCDEs in the PS stands for breathing assessment and maintenance. This second element in the PS emphasizes the importance of immediate identification and treatment of life-threatening conditions related to the process of breathing and the thoracic cavity at presentation, as well as the maintenance of ventilation throughout the resuscitation phase. Only immediately life-threatening conditions are treated at this time. Five immediately life-threatening conditions involving the thoracic cavity should be actively sought out (Table 8). Additional urgent but non-immediate life-threatening conditions e.g., myocardial contusion and aortic dissection) can occur in the chest and are diagnosed and treated during the SS (Volume 1, Chapter 14). Because these injuries do not present an immediate threat to life, they are not actively evaluated or treated during the PS. The key principles of the pertinent physical examination, radiographic data, and treatment goals of immediately lethal conditions are covered in this chapter.

Table 8 Immediately Life-Threatening Conditions

Tension pneumothorax	Accumulation of a large amount of air under pressure within the pleural space (Fig. 5)
Massive hemothorax	Accumulation of a large amount of blood in the pleural space, most often due to bleeding from an intercostal artery or from major central chest vessels (Fig. 6)
Sucking chest wounds	Open wound allowing air to be entrained into the chest during inspiration
Flail chest	Result of multiple ribs fractured in more than one place, allowing the chest wall to become unstable (Fig. 9)
Cardiac tamponade	Accumulation of blood in the pericardial sac under tension, resulting in a decrease in cardiac output. Blood in the pericardial sac most often results from penetrating injuries of the heart, though rupture of the right atrium or ventricle can occur after blunt trauma

Physical Examination

Inspection

The physical examination of the chest can be systematically organized into inspection, palpation, and auscultation, and all three methods should be accomplished expeditiously. Inspection of breathing efficiency begins with the assessment of the respiratory rate (RR) and pattern. The normal adult RR ranges between 10 and 30 breaths/min. In many life-threatening situations, patients may experience respiratory distress, reflected by an increased RR. Accordingly, the RR has proven to be a good indicator of life-threatening injuries to the chest (25). Inspection of the neck is important and should always be done when chest injuries are suspected (26). If the patient is wearing a collar, it should be removed (while performing the neck examination) and returned after the neck evaluation is completed. The neck should be examined for distended veins and deviation of the trachea.

Distended neck veins are a sign of increased intrathoracic pressure, as occurs with a tension pneumothorax, massive hemothorax, or cardiac tamponade. Distended neck veins with deviation of the trachea suggest tension pneumothorax or massive hemothorax. Distended neck veins without deviation of the trachea suggest cardiac tamponade. Paradoxical movement of the chest wall suggests flail chest.

In a state of hypovolemic shock, distended neck veins might be missing even in these situations (tension pneumothorax or cardiac tamponade). Tracheal deviation is a sign of unilateral tension pneumothorax, mainstem intubation with positive pressure ventilation, or massive hemothorax, as the trachea is pushed to the opposite side by air or blood under pressure.

Figure 3 Assymetric chest movement. This chest radiograph of a supine patient demonstrates decreased excursion of the chest wall on the right compared to left. This finding is consistent with multiple right-sided rib fractures or a left-sided tension pneumothorax.

The anterior and posterior torso must be completely exposed in order to fully evaluate the depth and symmetry of the chest excursions and to search for open chest wounds. Examination of the back is accomplished by "logroll" of the patient with one person specifically holding the head and neck in the neutral position while others help turn the patient and inspect the back. Be vigilant for paradoxical breathing (antagonist movement of part of the chest wall during respiration). An open wound with "bubbling" through the water seal chamber of the chest tube drainage collection device indicates continuity with the pleural space (and possibly a bronchopleural fistula). Asymmetric movement of the chest can mean tension pneumothorax, massive hemothorax, or flail chest segment (Fig. 3).

Palpation/Percussion

Identifying areas of tenderness or deformity of the chest is achieved by palpating the ribs and sternum gently. Crepitus is a fine "crackling" sound or sensation felt on the fingertips and is an indication of subcutaneous emphysema (Fig. 4). The presence of subcutaneous emphysema usually means that there is an injury to the airway, somewhere between the vocal cords and the alveoli. Tracheal and bronchial injuries are the most worrisome etiologies, but the "extra anatomic" air can also migrate from a pneumothorax, pneumomediastinum, or esophageal injuries.

While palpating the chest, one may feel a more gross form of crepitus due to moving rib fractures during ventilation. Percussion is uncomfortable to the patient and is generally relegated to evaluation in clinical settings without access to portable CXR (such as on the battlefield or in a field disaster triage center). Hyper-resonance during percussion suggests pneumothorax (Fig. 5), and flat or dull sounds indicate hemothorax (Fig. 6).

Auscultation

Auscultation is the last, but perhaps most important, step in the physical examination of the chest. Both lungs are auscultated to assess the quality of respiratory sounds,

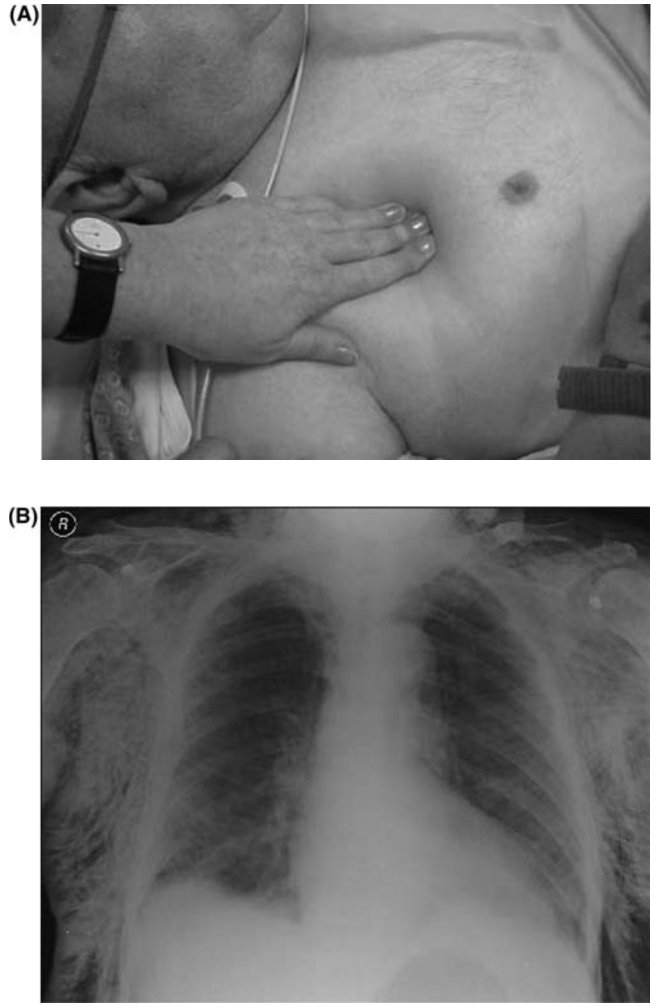

Figure 4 (**A**) Subcutaneous emphysema. This photograph of a supine male trauma patient demonstrates massive subcutaneous emphysema. The hand in the photograph is compressing the air away from the right upper chest, and in doing so would feel crepetance as the small air bubbles are displaced. (**B**) Subcutaneous emphysema on (CXR). This chest radiograph demonstrates bilateral subcutaneous emphysema extending from the chest wall up to the shoulders.

including the presence of equal ventilation on both sides. Diminished breath sounds may point to pneumothorax, hemothorax, or lung contusion.

Imaging Aids to Breathing Assessment

Tension pneumothorax, massive hemothorax, and cardiac tamponade should be clinically diagnosed and treated prior to CXR. In the trauma resuscitation bay, at least two modes of chest imaging should be performed: plain CXR and ultrasound of the pericardium. Ultrasound is done during the focussed assessment with sonography for trauma (FAST) (27). The FAST examination is now widely used at most major trauma centers. With the FAST examination, the trauma surgeon can diagnose a large hemothorax or pneumothorax, in addition to abdominal blood or pericardial blood. Injuries usually detected only after CXR or computed tomography (CT) scan include pulmonary contusion, rib fractures, small pneumothorax,

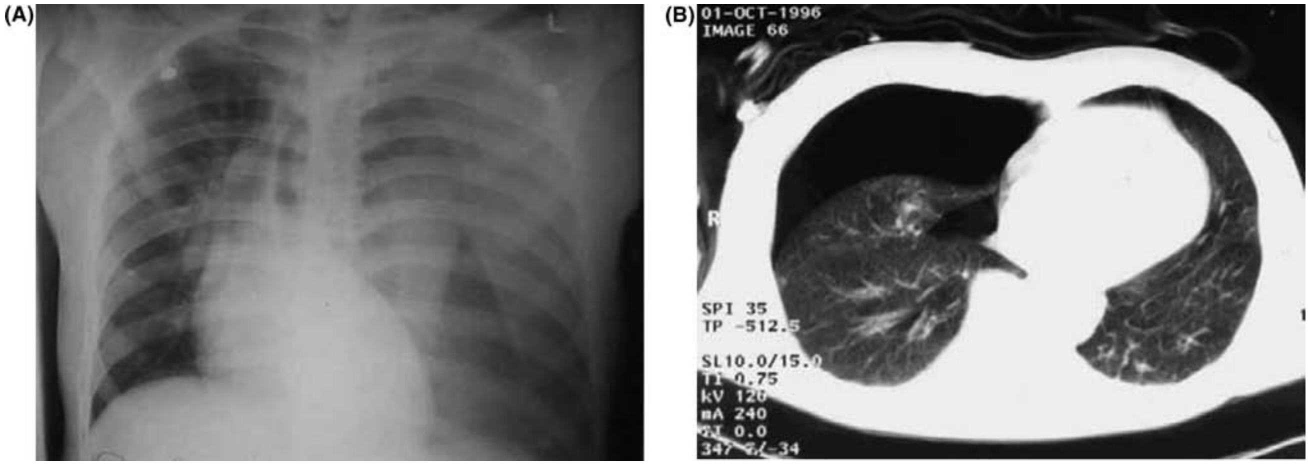

Figure 5 (**A**) Left-sided tension pneumothorax. Note, this patient also had blood in the left thoracic cavity, hence the increased opacity, despite the tension pneumothorax. After the chest tube was placed, the radiograph returned to almost normal (not shown). (**B**) Right-sided tension pneumothorax. This computed tomography scan demonstrates free air anterior to the right lung and shift of the mediastinal structures from the right toward the left. After the chest tube was placed, the radiograph returned to normal with return of the mediastinum to the anatomic position (not shown). In addition, the patient's hemodynamic status and oxygenation returned to normal immediately thereafter.

Figure 6 Massive left-sided hemothorax. This anterior–posterior chest radiograph demonstrates a shift in the mediastinum from the left toward the right, and very little aeration of the left lung due to the massive nature of the left-sided hemorrhage.

or small hemothorax. A tension pneumothorax or massive hemothorax can usually be diagnosed on clinical evaluation alone during the PS and both can be treated with a thoracostomy tube prior to CXR (28).

Aortic rupture may be suggested on CXR when there is widening of the mediastinum (Fig. 7), loss of the aortic knob contour, shift of the esophagus [nasogastric (NG) tube] to the right or apical cap. However, definitive diagnosis and staging occurs during the SS survey (Volume 1, Chapter 14) using CT angiography as reviewed in Volume 1, Chapter 25 (29).

Although, pneumomediastinum can occur secondary to tension pneumothorax and bronchopleural fistula, this can also result from tears of the esophagus, trachea, or main bronchus (entities diagnosed during the SS). Loss of diaphragmatic contour, the presence of bowel or an NG tube in the chest, or elevation of the left hemidiaphragm (Fig. 8) are all suggestive signs of diaphragmatic rupture.

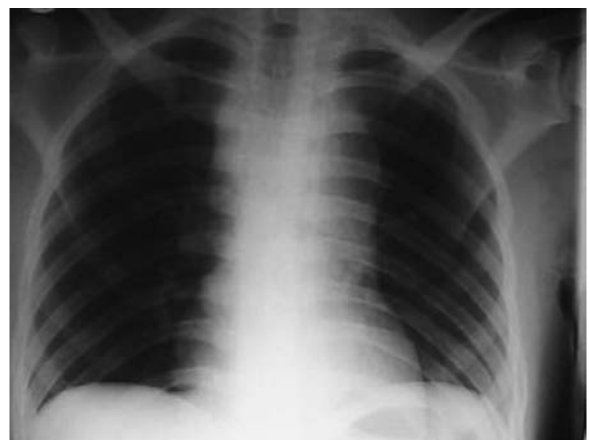

Figure 7 Widened mediastinum. Also, note loss of aortic contour. When trauma patients present with a chest radiograph demonstrating these findings, an aortic tear should be ruled out (usually by computed tomography angiography).

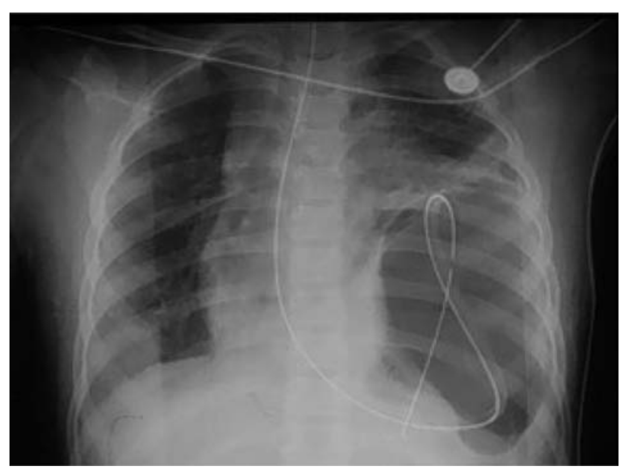

Figure 8 Diaphragmatic rupture. This anterior–posterior chest radiograph demonstrates massive elevation of the left hemidiaphragm and the stomach (along with the nasogastric tube) in the left chest cavity.

Life-Threatening Thoracic Injuries

As soon as a life-threatening injury is diagnosed during the PS, it should be treated. The following five immediately life-threatening conditions that occur in the thoracic cavity should be specifically and aggressively pursued: (*i*) tension pheumothorax, (*ii*) massive hemothorax, (*iii*) sucking chest wound, (*iv*) flail chest, and (*v*) pericardial tamponade.

Tension Pneumothorax

When tension pneumothorax is suspected (Fig. 5), decompressing the pressure in the chest is the first goal. The venous return to the heart is diminished by the high pressure in the chest, and subsequent deviation of the heart can cause distortion or "kinking" of the vena cava. To preserve lung and heart function, the injured side must be decompressed immediately, preferably with a chest tube.

Needle thoracostomy, or a self-contained system such as the "McSwain Dart," is sometimes instituted en route to the hospital as a temporizing decompressive procedure. **Whenever a needle thoracostomy is used, it must be followed up by placement of a chest tube.**

Massive Hemothorax/Tube Thoracostomy

Massive hemothorax (Fig. 6) will not be resolved by "needle thoracostomy" alone. The accumulated blood in the chest results in the same physiological changes as a tension pneumothorax, added to which is a hypovolemic state compounding the effects on hemodynamics. Hemothorax should be initially controlled by the placement of a chest tube.

If more than 1500 mL of blood is evacuated after the initial chest tube placement, or drainage of more than 200 mL/hr persists for two to four hours, consideration should be given to operative exploration (26).

The technique for chest tube placement is as follows. The fifth intercostal space, just anterior to the midaxillary line, is the preferred site for chest tube insertion in trauma. Because actual counting of the spaces can be problematic, the fifth intercostal space can be estimated. In men, it is located immediately above the nipple-line along the midaxillary line. In women, the lower extent of the hairline under the axilla approximates the fifth intercostal space. The tube should never be inserted through breast tissue. The site is prepped with provodone/iodine and/or Hibacleans™ alcohol and anesthetized with lidocaine 1% to 2% using up to 20 mL. In hemodynamically stable patients, conscious sedation can supplement the local anesthesia with careful titration of a short-acting opioid and a benzodiazepine. After making a 3 to 4 cm incision, a large-curved hemostat is used to puncture the intercostal muscles and parietal pleura immediately along the superior rib border, avoiding damage to the neurovascular bundle (located underneath the rib), as well as the underlying lung. A digital examination is performed to evaluate for pulmonary adhesions and to assess lung location.

To avoid losing the desired tract, the finger is kept in place until the tube is inserted along the side of the guiding finger. A clamp is typically used to help advance the tube past the guiding finger into the desired position. The chest tube is then directed posteriorly (if for hemothorax), or superiorly toward the apex (if for pneumothorax), until it is at least 5 cm beyond the most proximal hole of the tube. In many patients, cutting off 4 to 6 cm of the tip of the tube prior to insertion helps ensure that the proximal hole can be fully positioned within the thoracic cavity.

The tube is then attached to a water seal and vacuum device (e.g., Pleur-Evac). Respiratory variations are evaluated and bubbling of air through the water seal is indicative of a broncho-pleural fistula. The amount of blood or other fluid that drains is documented. The insertion site is sutured to secure the tube. A suitable dressing is applied, and follow-up CXR is required to confirm the tube placement and lung re-expansion.

Sucking Chest Wounds

The size of the chest wound will determine the magnitude of the pulmonary compromise—the larger the defect, the more it will interfere with normal negative pressure generation occurring during inspiration and the greater the degree of lung collapse that will occur. Small wounds can trap air inside the thoracic cavity like a "one-way valve" leading to tension pneumothorax.

Treatment of sucking chest wounds in the field begins with coverage using a sterile occlusive dressing. The dressing is taped on three sides so that it can act as a one-way valve, allowing air to exit the chest during exhalation, but preventing air entrainment during inhalation. Alternatively, commercially manufactured "Heimlich valves" can be placed. If the patient's state deteriorates after placing the dressing, it must be removed immediately. In the case of a large open wound that cannot be occluded, the patient must be intubated and ventilated to survive the injury.

In the resuscitation bay, these lesions are treated with a chest tube. The wound itself should not be used for insertion of the tube, even if its size appears perfect, because of potential bacterial and foreign material contamination. Massive wounds not treatable with a chest tube will require intubation and mechanical ventilation in the resuscitation bay as well.

Flail Chest

Flail chest is an injury to the ribs where a section of the chest wall has been detached due to fractures of two or more ribs, in two or more places. Pulmonary contusions often occur in areas of lung underlying a flail segment (Fig. 9). These factors result in impairment of ventilation and oxygenation. The treatment for flail chest is usually intubation and

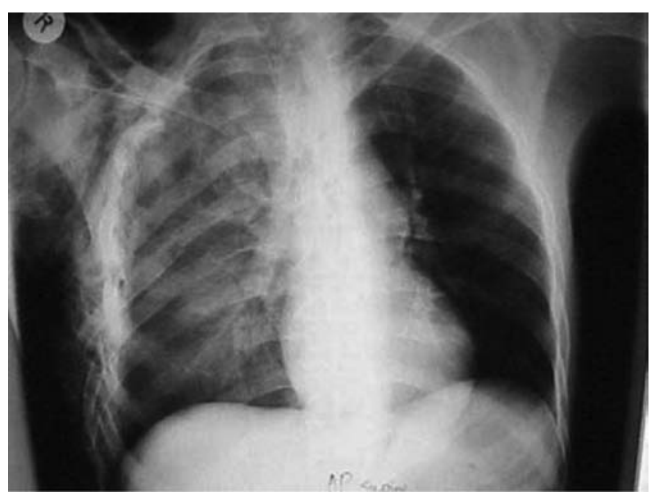

Figure 9 Right-sided flail chest. This anterior–posterior chest radiograph demonstrates multiple contiguous right-sided rib fractures, along with some subcutaneous emphysema and some underlying right-sided pulmonary contusion.

mechanical ventilation, along with intravenous analgesia and sedation until the fractured ribs stabilize and ventilation improves as pain diminishes three to five days later. Some advocate internal fixation of flail segments (30), but this is rarely done and only on a case-by-case basis. Pulmonary contusion, when present, is treated with mechanical ventilation, analgesics, and supportive care. In patients with painful flail segments and without significant pulmonary contusion or other lung parenchymal injuries, the pain can be treated with thoracic epidural analgesia, and these patients can be more quickly transitioned to spontaneous ventilation and extubation (Volume 2, Chapter 25).

Cardiac Tamponade/Pericardial Drainage

Cardiac tamponade is a life-threatening condition caused by blood accumulating under pressure within the pericardial sac. This prevents the heart from expanding and filling completely during diastole. Accordingly, the stroke volume is markedly diminished. In penetrating trauma, blood usually accumulates quickly, and the rapid increase in pericardial pressure causes a progressive decrease in cardiac output. The initial diagnosis of hemopericardium is often suggested by a large cardiac silhouette on CXR and can be confirmed by the FAST examination (Fig. 10). The patient with acute cardiac tamponade should be transferred to the OR for surgical drainage if time allows. If not, a pericardiocentesis or thoracotomy should be immediately performed in the resuscitation suite.

"Needle pericardiocentesis" is only a temporizing procedure. After relieving the tamponade, the catheter should remain in the pericardial sac (for further drainage), and the patient should then be transported to the OR for a definitive treatment. The blood in the pericardium sometimes clots and often cannot be fully aspirated through the pericardiocentesis needle. Additionally, needle aspiration will not assist in diagnosing the source of the bleeding or treating the primary cause. Pericardial fluid of medical etiologies is often suitably treated with a subxyphoid window. However, traumatic etiologies often require a formal stenotomy.

A technique for performing a "needle pericardiocentesis" is as follows: the patient must be breathing 100% O_2 monitored with an arterial line, pulse oximetry, and ECG as a minimum. A large-bore cannula is slowly inserted immediately to the left of the xiphoid process, aiming for the tip of the left scapula. The cannula is aspirated constantly until blood appears while watching the monitor for cardiac dysrhythmias (which appear if the needle is inserted into the cardiac muscle). If dysrhythmias are encountered, the needle is pulled back and re-directed. When blood is aspirated, the tamponade can be aspirated (often with dramatic improvement in the patient's vital signs). A wire is then passed through the needle and into the pericardial sac, and after removing the needle, a catheter is placed over the wire into the pericardial space (Seldinger technique). The cannula is left in place for further pericardiocentesis until the definitive procedure (either a subxyphoid window or formal sternotomy to evaluate and treat bleeding sites) is complete. Other conditions that are not an immediate threat to life are diagnosed and treated after the PS is completed.

Mechanical Ventilation in the Resuscitation Suite

All intubated trauma patients should be ventilated during the PS using a small transport ventilator (discussed

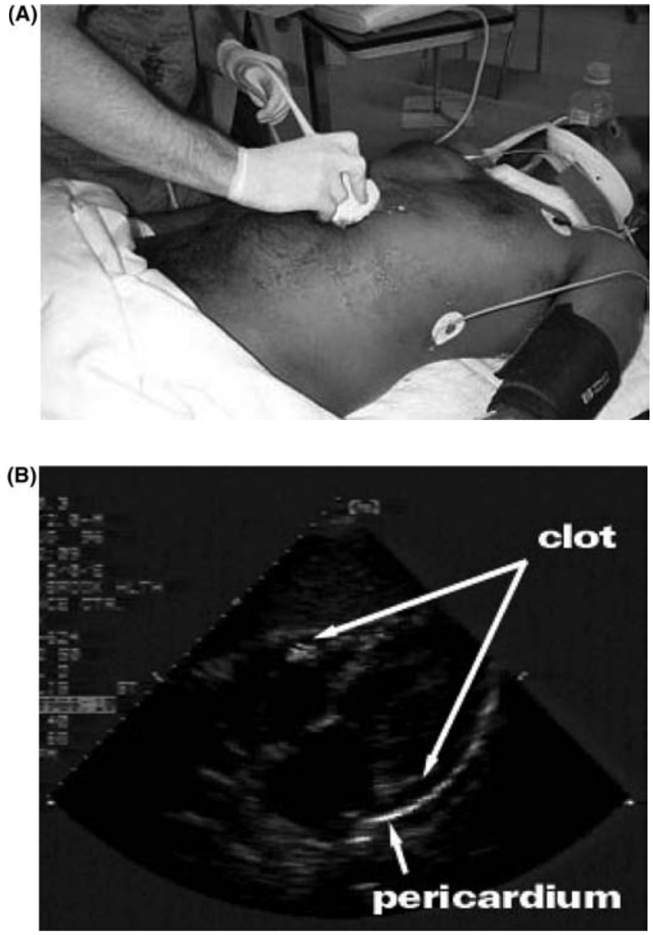

Figure 10 (**A**) Pericardial scanning during focused assessment with sonography for trauma (FAST) examination. FAST is part of the secondary survey (regarding abdominal and pelvic blood), but could be considered part of the primary survey with regard to the pericardial survey for pericardial effusion (blood)/cardiac tamponade. Here, the echo probe is being aimed toward the pericardial sac from the subxyphoid region (Fig. 10B). (**B**) Pericardial tamponade. The ultrasound image of pericardial blood (some of which appears to have clotted) is seen in this supine patient who suffered a stab wound to the right ventricle.

subsequently and in Volume 1, Chapter 5). Ventilated patients should only receive analgesia and sedation if hemodynamically stable. Unstable patients should not receive any drugs that might further destabilize them; however, scopalamine can be administered to prevent recall (Volume 1, Chapter 19). The goals during this critical period are simply the provision of adequate oxygenation and ventilation. Oxygenation adequacy for systemic oxygen delivery (DO_2) is initially verified by pulse oximetry: S_aO_2 must be above 94%. Ventilation adequacy is initially verified by end-tidal $P_{ET}CO_2$. An arterial blood gas will provide an accurate measurement of P_aO_2 and P_aCO_2 to allow evaluation of the shunt (A-a) gradient and the alveolar dead space ($P_{ET}CO_2$-P_aCO_2 gradient).

When choosing a ventilator for trauma patients in the resuscitation suite, reliability, mobility, and simplicity are the most important characteristics. The ventilator must have the ability to provide 100% oxygen, high-pressure limits, the capability to apply PEEP, have easy adjustments for rate and tidal volume, I:E ratio, and the earlier described parameters. Humidification can be provided using a condenser humidifier.

Most commercially available "transport" ventilators are suitable for these purposes. When selecting a new brand of machine, it should be tested under extreme conditions. The critical elements required for reliable use in the resuscitation suite and during transport are (*i*) size, as small and light as possible; (*ii*) durability, strong enough to withstand falls and abuse; and (*iii*) power, should be able to work without an external power source. In all cases, the duration of function without an external power source must be checked. The necessary alarms are disconnection alarm, low-oxygen alarm, high-pressure alarm, and low-battery alarm.

The operation of the ventilator should be simple, taking into account that the trauma team (physicians and nurses) are often too busy evaluating, resuscitating, and treating the patient to deal with complicated ventilator settings. The more complicated and sophisticated the ventilator, the greater the range of possible errors. These patients must be transferred to the SICU as soon as possible, where special ventilators and additional knowledge are found (Volume 2, Chapters 25–27).

CIRCULATION ASSESSMENT AND HEMORRHAGE CONTROL

Assessment

Evaluation of the circulation during the PS involves (*i*) assessment of the circulatory perfusion and volume status, (*ii*) control of hemorrhage, (*iii*) restoration of intravascular volume if depleted, and (*iv*) frequent re-evaluation. Errors during PS of the circulation are a frequent source of increased mortality and preventable deaths (31).

Compensated circulatory deterioration in a severely injured, previously healthy patient may be misinterpreted as hemodynamic stability and result in inadequate or delayed treatment. Therefore, minimizing the probability of unrecognized blood loss, reducing underestimation of hypovolemia, and prompt identification of causes unrelated to volume status that provoke hemodynamic instability are essential to the successful early management of trauma patients. Assessment of hemodynamic stability needs a clear definition, accurate processing, and continuous re-evaluation.

Definition of Hemodynamic Stability

Hemorrhage is considered as the primary source of hemodynamic instability in trauma patients until proven otherwise. Hemodynamic stability represents adequate blood flow and organ perfusion. Measurement of these variables can be difficult and time-consuming. Therefore, expedient assessment of hemodynamic status must rely on simple variables that are easy to determine, including HR, BP, RR, level of consciousness, capillary refill, and character of pulse.

The ACS Committee on Trauma has established a classification system for the extent of hemorrhage (Table 9) (26). Per ATLS guidelines, the initial IV fluid resuscitation should consist of a 2000 mL Ringer's lactate bolus. If hypotension persists or is recurrent, immediate blood transfusion should commence.

Patients who are transferred from other institutions, or have a delay in presentation, can manifest "third-space" fluid losses in addition to blood loss. Accordingly, in these patients, the degree of post-traumatic fluid permeability

Table 9 American College of Surgeons Classification System for Extent of Hemorrhage

Class I	Blood loss is less than 750 mL if heart rate is less than 100 bpm and blood pressure unchanged
Class II	Patients with a pulse rate >100 bpm, decreased pulse pressure, and oliguria have a blood loss of 750–1000 mL
Class III	Patients with hypotension, tachycardia >120 bpm, oliguria, and confusion have a blood loss of 1500–2000 mL
Class IV	Patients with a pulse rate >140 bpm, severe oliguria, and lethargy have a blood loss >2000 mL

Abbreviation: bpm, beats per minute.

and edema development should be treated with fluid resuscitation considered during the PS. Hemodynamic instability should be treated with fluid resuscitation until emergency diagnostic procedures are accomplished and relevant injuries are excluded.

Circulation Assessment Principles

Initial Global Evaluation of Circulatory Status

Assessment of circulation starts with a first general view of the trauma patient when technical monitoring support has not yet been established. The objective is to identify patients at risk for traumatic exsanguination. This should be accomplished within a few seconds.

Blood-stained apparel and clots on the gurney can provide visual evidence of extensive bleeding. However, even without obvious external clues, the presence of pallor, diaphoresis, or decreased level of consciousness suggests the presence of hemorrhagic shock. Pulse should be palpated to identify its presence and quality. Both tachycardia and bradycardia can be found in hypovolemia. However, classically, hemorrhage is accompanied by a rapid and shallow pulse.

A decreased level of consciousness is generally obvious, but should be quantified using the Glasgow Coma Scale (GCS). RR and depth of breathing are inspected at the same time, providing first information about a non-bleeding injury that can provoke hemodynamic instability such as tension pneumothorax (discussed earlier).

Information from paramedics or other prehospital emergency providers is helpful in the assessment of blood loss and circulatory state prior to arrival. However, the precision with which prehospital personnel accurately report prehospital blood loss is notably poor (32). Uncontrolled bleeding at the accident site, deterioration of patient status, and declining BP or frank hypotension during transport are indicators for evolving circulatory instability during early in-hospital treatment. RR, HR, systolic blood pressure (SBP), the GCS, and the elements of the revised trauma score (RTS) are the evaluation parameters sought during the PS when assessing life-threatening disorders (33).

Heart-Rate/Shock Index

Raised HR infers diminished intravascular volume, but is modified by vagal tone, emotional stress, pain, and drugs. A primary compensation for hemorrhage is normally raising HR and contractility combined with increased peripheral resistance (34). Accordingly, the HR is a valuable parameter for circulatory assessment. An HR of more than 100 beats per minute (bpm) is treated as shock until proven otherwise.

The shock index (SI), defined as the ratio of HR divided by the SBP, has been proposed as an assessment of circulation. An SI greater than 0.9 is presented as a better tool to identify critically ill patients than the HR or the systolic (or diastolic) BP alone (35). In one study of trauma patients, the optimal SI threshold was found to be similar to the optimal threshold HR or SBP for prediction of injury severity (36). Nevertheless, neither BP nor HR directly reflects cardiac output during emergency resuscitation or critical illness (34). Indeed, cardiac output may be decreased in the setting of increasing HR when the stroke volume is falling to a greater degree (Volume 2, Chapters 3 and 9). Pain and emotional factors raise HR after trauma. Medications such as beta-blocking agents, digitalis, or injuries of the spinal cord hinder compensational tachycardia and produce bradycardia despite severe blood loss and hemorrhagic shock.

Blood Pressure

Measurement of BP is one of the first steps in the assessment of circulation in trauma patients with a potential for bleeding. There is an ongoing debate on the relative value, or even harmfulness, of normalization of BP for bleeding trauma patients during prehospital and initial in-hospital treatment, focussing on the potential for worsened bleeding from fluid resuscitation in patients with penetrating trauma (37).

Lowered BP on admission is one of the most important signs of hypovolemia and exsanguination and requires efforts aimed at hemorrhage control. Although it is unclear as to what level of BP can be accepted for adequate organ perfusion, one cohort of bleeding patients associated with a high mortality rate of 69% demonstrated an MAP = 63 mmHg in the ED (38). Thus, options and limitations of BP measurement (Volume 2, Chapter 9) must be known to interpret the results reasonably.

Noninvasive blood pressure (NIBP) measurement with automated devices is the most common initial method used, permitting rapid automatic and repetitive measurements. However, initial measurement of BP demonstrating "normal" values should be considered suspect (as a reflection of euvolemia), and subsequently repeated at regular intervals due to the underlying compensation for hemorrhage. The "stress–response" to hypovolemia, (with endogenous catecholamines, neural mechanisms, and pain from injuries) generally leads to a brief rise in BP during the early phase, despite lowered blood volume and cardiac output from bleeding. Compensatory mechanisms will inevitably become overwhelmed by prolonged hemorrhage and hypovolemia. Often BP drops precipitously as compensation is lost, though blood flow may have been marginal for some time prior to the drop (39).

Thus, repetitive BP measurements during diagnostic and therapeutic procedures are mandatory to anticipate and monitor impending hemodynamic decompensation. Patients with tenuous BP values need closer supervision and rapid diagnostic procedures to avoid further deterioration.

Pulse oximetry can also be helpful in detecting diminished perfusion. When the patient begins to vasoconstrict peripherally due to hypovolemia, the pulse oximetry signal may become intermittent and difficult to detect. This problem is often improved by volume resuscitation. **Hypotension is the most common indication of circulatory dysfunction in trauma. Nevertheless, normal BP does not exclude circulatory impairment following trauma, as 30% of the blood volume may be lost before hypotension begins to occur.**

Body Temperature

Mild hypothermia (35.9–35°C) will result in sympathetic activation. Physiological changes are tachycardia and increased peripheral vasoconstriction and cardiac output (40). Moderate hypothermia (34.9–32.5°C) is associated with a progressive decrease in HR and cardiac output and increased atrial and ventricular dysrhythmias. Severe hypothermia (<32.5°C) produces progressive decreases in BP, HR, and cardiac output with final asystole. Therefore, assessment of hemodynamic status must incorporate early measurement of body core temperature.

Additional vasoconstriction due to hypothermia can obscure circulatory impairment caused by bleeding as evaluated by BP measurements. However, the vasoconstriction from hypothermia will exacerbate the pulse-oximetry-mediated clues of under perfusion (i.e., inability to detect pulse-detecting signal).

A reduced core temperature needs special attention not only for circulatory treatment, but also for pathophysiological problems of rewarming and coagulopathy (Volume 1, Chapter 40) (41,42). **Hypothermia can modify circulatory response to trauma.**

Urine Output

Monitoring urine output is essential in the ongoing assessment of circulation. However, the duration of the PS is generally too fleeting for urine output to be of value. Nonetheless, urine output is followed during resuscitation and throughout the SS. Normal urine output is approximately 1.0 mL/kg/hr, but it often requires more than 15 to 30 minutes to obtain meaningful results. Reduced or declining urine output indicates deterioration of hemodynamics due to shock, bleeding, or inadequate fluid resuscitation. Patients with increased osmotic loads due to hyperglycemia, ethanol intoxication, and mannitol treatment may have elevated urine output despite hypovolemia. Normal urine output is one of the standard endpoints of resuscitation and reflects adequate renal perfusion pressure and sufficient fluid replacement. **Urine output is an important but not an immediate indicator of intravascular volume and systemic perfusion.**

Circulatory Depression from Nonhemorrhagic Causes

Although hypotension in the trauma patient should initially be assumed to result from hemorrhage, circulatory depression can also occur due to nonbleeding injuries and other sources. Hypotension can arise from the increased thoracic pressure that results from hemothorax, pneumothorax, or diaphragmatic rupture (described earlier). Additionally, pericardial tamponade or myocardial ischemia can result from injury to a coronary artery during trauma or due to progression of pre-existing coronary artery disease and a diminished supply/demand profile during hemorrhage. Ischemia can be detected by ST depression or elevation on ECG. Spinal cord injuries are another source of hypotension manifesting as vasodilation and bradycardia. **Injury to the spinal cord will exacerbate any hemorrhage-induced hypotension because the normal sympathetic compensation to hypovolemia is lost.**

Management of Compensated Hemorrhagic Shock

The PS involves assessment of the patient's vital functions. Stable systems on admission do not exclude deterioration. Concise assessment and anticipation of deterioration are basic principles in trauma management. Experience and skills must be available if there is any doubt.

Shock Prediction and Prevention

Shock prediction and prevention are essential elements of early trauma management. Possible bleeding sources causing future decompensation must be excluded. After the initial evaluation, diagnostic procedures should identify obvious and occult bleeding. Clinical examination can exclude external bleeding, as well as open fractures and most closed fractures. Immediate X-ray of the thorax and pelvis excludes bleeding in both regions. Abdominal examination using FAST can reveal free liquid representing blood at an early stage. FAST has substantially replaced diagnostic peritoneal lavage (DPL) in many parts of the world and should be available in every trauma unit. The staging of abdominal injuries is reviewed in Volume 1, Chapter 27.

Blood samples for relevant laboratory tests [especially Hgb, Hct, platelets, an arterial blood gas (ABG), and lactate] should be obtained to evaluate and re-evaluate patient status. Parameters of blood coagulation, such as prothrombin time (PT) and partial thromboplastin time (PTT), are essential for diagnosing coagulopathies, especially in unconscious or hemorrhaging patients. Minimal trauma can cause significant bleeding with disastrous results if anticoagulation is present.

Maintenance of Blood Pressure and Tissue Perfusion

The conventional resuscitation approach presently favors maintaining BP and tissue perfusion until blood loss is controlled with fluid resuscitation to avoid lactic acidosis and organ failure. Although raising BP can increase tissue perfusion and tissue oxygenation, it can also worsen bleeding and impair formation of new blood clots or dislodge the existing ones (43). Predictive factors for mortality in the exsanguinated patient have been identified. They are pH ≤ 7.2, temperature $<34°C$, blood replacement >4000 mL, fluid replacement $>10{,}000$ mL, and/or estimated blood loss >15 mL/min (44).

The absolute BP per se has not been a consistent predictive parameter. However, the practical approach involves the titration of BP with fluid resuscitation, taking a middle ground between maintaining the $\dot{Q}$ and cerebral perfusion, versus increasing the head of pressure so much that hemorrhage is exacerbated.

To avoid the triad of hypothermia, acidosis, and coagulopathy or even cardiac arrest in severely bleeding patients, staged surgical laparotomy (i.e., "damage control") has been proposed (Volume 1, Chapter 21) (45).

Management of Uncontrolled Hemorrhagic Shock

Uncontrolled hemorrhagic shock from trauma has an extremely high mortality (46). Death at the scene or on arrival occurs in many of these patients. Uncontrolled hemorrhage was found in nearly 50% of patients whose SBP was below 90 mmHg and in 66% of those patients whose SBP was below 50 mmHg (46). The predominant cause was penetrating or blunt trauma with laceration of the great thoracic or abdominal vessels due to high-speed deceleration, fall, or firearms.

Major vessel injury is seen in 5% to 25% of patients admitted to the hospital with abdominal trauma (47). The three vessels with the highest mortality rates when injured include the aorta (91%), hepatic veins and/or retrohepatic vena cava (88%), and portal vein (69%) (47). These injuries usually require immediate surgical control for survival to occur.

Identification of hemorrhagic shock in the prehospital setting requires immediate transport, along with the notification of the trauma team to prepare for immediate diagnosis and treatment of uncontrolled hemorrhage. These patients should be transported directly to the trauma OR (Volume 1, Chapter 5).

Initial normalization of BP with fluid resuscitation in patients with uncontrolled bleeding is no longer a common goal in the prehospital setting or in the resuscitation bay. Successful management must focus on identifying sources of bleeding and initiating definitive care while achieving the minimal perfusion pressure required to maintain "adequate" cardiac and cerebral function. "Normalization" of BP with fluid resuscitation occurs after control of bleeding and is aimed at minimizing organ damage from hemorrhagic shock. **Trauma patients with uncontrolled hemorrhagic shock require damage control surgery without time delay.**

Diagnostic Testing and Monitoring Adjuncts

Hemoglobin Measurements

Hemoglobin admission level is a common parameter for estimating blood loss. A low Hgb level is considered as an indicator of serious ongoing hemorrhage after injury. This parameter has important implications for further management and prognosis. In 31 patients with initial Hgb levels of <8 g/dL, the overall mortality was 48.4% when compared with 2.6% in 969 patients with initial Hgb level ≥ 8 g/dL (48). Nevertheless, even extremely low hemoglobin levels are tolerated if intravascular volume is restored (49). When interpreting the hemoglobin level, one needs to consider the extent of dilution due to prehospital fluid resuscitation with crystalloids or colloids. **Normal Hgb levels do not assure that the patient has not sustained significant blood loss.**

Invasive Blood Pressure Monitoring

Invasive BP measurement provides continuous information about the patient's hemodynamic status and is commonly used in the OR and ICU. Changes in BP will be detected earlier, and interpretation of the arterial pressure waveform provides additional information on the volume status, contractility, and afterload of the patient.

Central Venous Pressure

Central venous pressure (CVP) reflects right atrial pressure and provides information concerning volume status. Its reliability has been questioned due to methodological problems and interference with ventilation (50). However, experienced practitioners find the placement of large-bore CVP lines useful for rapid fluid administration, the continuous monitoring of intravascular volume, and infusion of vasoactive drugs.

Placement of arterial lines and central lines typically occurs after the PS, either at the initiation of the SS or in preparation for surgery, but they are critical to optimal ongoing management.

Ideally, a competent individual is quickly and expertly placing such lines in large dedicated trauma centers and/or immediately present for supervising junior people. The approach of relegating these invasive lines (or even large-bore peripheral IVs) to junior inexperienced members of the trauma team is inappropriate. The supervising physician must be present and willing to quickly take over procedures in patients, who are difficult to cannulate. These severely injured patients require that such intravascular access techniques be executed with proficiency and speed, as sites and opportunities may be limited.

Arterial Blood Gas and Base Deficit

Analysis of the ABG (which measures pH, P_aO_2, P_aCO_2, and bicarbonate) provides information on the oxygenation, ventilation, and metabolic status of the patient.

Assessment of gas exchange, staging the severity of shock, and gauging the adequacy of resuscitation are the principal advantages of obtaining an ABG. The base deficit (BD), which represents a nonspecific indicator of metabolic acidosis, is estimated as an expedient and sensitive measure of both the degree and the duration of inadequate perfusion and ongoing hemorrhage (51,52). In trauma patients, a persistently elevated BD (i.e., more negative base excess) is associated with altered oxygen utilization and an increased risk of multiple organ failure and mortality (53). The BD trend helps to guide early and aggressive therapy for trauma/hemorrhage-induced tissue hypoxia (54). Rutherford et al. (51) identified a BD of 15 mmol/L as predictive of a 25% mortality rate among trauma patients younger than 55 years of age without TBI. Advanced age or the presence of TBI reduced the tolerance of BD. A BD of 8 mmol/L predicted a 25% mortality rate in trauma patients 55 years of age or older without TBI, as well as in patients <55 with TBI (51). Thus, BD serves as an important early indicator of resuscitation adequacy.

Lactate Level

Traditionally, an elevated blood lactate level after hemorrhage is interpreted as tissue hypoperfusion, hypoxia, and anaerobic glycolysis. The severity and duration of the increase in blood lactate levels correlate with death (55). Early lactate measurement in the resuscitation suite can help to determine therapy strategies and to find appropriate endpoints of resuscitation of trauma patients (56). No one has yet shown improved outcomes with sodium bicarbonate administration at any specific lactate or BD level. Thus, resuscitation is mainly fluid-based, with bicarbonate therapy being empirically administered at various thresholds around the world.

Over time, the administration of large quantities of normal saline can convert a metabolic acidosis due to lactate (reflecting underperfusion) into one resulting from excessive chloride ions (introgenic). Thus, lactate must be measured in the setting of metabolic acidosis to determine the adequacy of resuscitation. The anion gap will also be elevated when lactate is the etiology of metabolic acidosis.

FAST Versus DPL Versus CT Scan

Clinical examination of the abdomen is notoriously unreliable following blunt abdominal trauma, especially in the settings of competing pain or altered mental status. In unstable patients, without another reason to go to the OR, rapid objective evaluation of the abdomen is mandatory. Both FAST and DPL are used for this purpose. **The FAST examination is noninvasive, more rapid, and less expensive than DPL, but can also miss some injuries (57).** Indeed, a 28% incidence of liver and spleen injury visible on CT scan without significant free fluid in the abdomen was missed by FAST (58). The main function of the FAST examination is to rule in or out large quantities of free fluid in the abdomen and pericardial sac. In hemodynamically stable patients, the FAST examination or CT scan can be used (56). The FAST examination should be followed up with CT scan when equivocal results are obtained, when retroperitoneal injuries are suspected, and to stage injuries detected by the FAST (see (Volume 1, Chapter 27).

CT Scan

The need for a CT scan in severely traumatized patients is obvious. However, CT scanning is part of the SS and should not be used in hemodynamically unstable patients. As a screening tool for aortic injury, CT scan has a 100% negative predictive value if there is no periaortic hematoma (59).

CT scan is the imaging tool of choice for injuries involving the retroperitoneum. The diagnosis of periaortic hematoma (Zone I) increases the likelihood of significant intra-abdominal injury and, when associated with other intra-abdominal findings, indicates a need for operative exploration (60). **Hemodynamically unstable patients should go to the OR rather than the CT scanner.**

DISABILITY

General Considerations

A rapid neurological examination is performed during the PS, immediately after identifying life-threatening injuries related to the airway, breathing, or circulation (26). The check for unresponsiveness of a patient is a primary task of the basic life support (BLS) assessment phase and also has to be considered as part of the PS in trauma patients (61). Therefore, the "D" in the PS of the trauma patient refers to "neurological disability," including any injury to the central or peripheral nervous system.

A brief neurological examination should always be completed at the scene (and documented) by the EMS providers prior to the administration of drugs which could alter neurological function. The results of these examinations are thus compared with the neurological examination performed immediately upon arrival in the resuscitation suite.

A decreased level of consciousness should initially be attributed to hypoxia, hypovolemia, TBI, or hypoglycemia (62). However, the effects of drugs, alcohol, hypothermia, and metabolic causes should also be considered. Any alteration in neurological examination should be evaluated immediately by (follow-up) CT scan (63,64).

In any emergency patient, the neurological portion of the PS should be completed within one to two minutes. All findings of this examination must be documented in the patient's chart and factored into the evaluations of airway, breathing, and circulation.

History

Mechanism of Injury

Knowledge of the mechanism of injury helps the traumatologist recognize the most likely neurological injuries. It can be predicted, for example, that a patient who fell from a height of more than 5 m is likely to present with a complex injury pattern including various kinds of neurological disability (e.g., from cerebral or spinal trauma).

Patient History

An outline of the patient's history should be obtained as early as possible, ideally first at the scene. This can be achieved by directly questioning the patient or, if the patient cannot communicate, receiving information from relatives or bystanders, as well as seeking clues from "medic-alert" bracelets, surgical scans, medications found in handbags, and so on. Whether or not this precedes examination, treatment will depend on the acuity of the symptoms and the urgency of treatment.

To correctly judge any neurological disability, it is valuable to know whether the patient was suffering from any pre-existing head injuries, cognitive limitations, or seizure disorders. A general medical history including cardiac, pulmonary, and metabolic status, as well as medications, should also be detailed. **A useful mnemonic for obtaining a rapid history is AMPLE: allergies, medications, past medical history, last ate/drank, events leading up to the incident.**

Physical Examination

The neurological examination of the trauma patient occurs coincident with the evaluation of airway, breathing, and circulation (65). Clinical symptoms of TBI can be quickly gauged by evaluating three items: level of consciousness, pupillary function, and lateralized weakness of the extremities (Table 10). The level of consciousness is assessed as part of evaluation of the GCS, which enables its user to rapidly determine neurological disability.

Table 10 Clinical Signs of Head Injury

Decreased level of consciousness
Pupil size and reaction altered
Hemiparesis, hemiplegia
Cranial deformity and swelling
Leak of cerebrospinal fluid
Hemotympanum
"Raccoon eyes"
Seizures
"Battle's sign" [postauricular (mastoid) ecchymosis]

Level of Consciousness—Glasgow Coma Scale

The GCS, developed in 1974, is the most widely used system for level of consciousness assessment in trauma (66). The GCS is not only predictive of outcome but also simple to use, with low intraobserver variability (67–70). The GCS is calculated by adding the values obtained in each of the three components eyes (1–4), motor (1–6), and voice (1–5) resulting in a final score from 3 to 15 points (Table 11) (71,72). The GCS is fully described elsewhere (Volume 1, Chapters 4 and 23 and Volume 2, Chapters 7 and 12).

The GCS not only helps to rapidly assess the patient's neurological function, but also serves as a guideline for initial patient management including the need to intubate, obtain a brain CT scan, and/or monitor ICP. An aggregate GCS of ≤8 represents a severe TBI, GCS 9 to 12 signifies a moderate injury, and GCS 13 to 15 denotes a minor injury. As a general rule, patients achieving a GCS of ≤8 need intubation due to compromised airway reflexes. Repeated GCS scoring, starting in the prehospital setting and extending into the hospital resuscitation phase, can also demonstrate decreasing scores and thus the need for more urgent intervention (73).

Pupil Examination

In addition to the level of consciousness, the pupils are assessed for size, equality, and response to bright light. The response to light should be rapid and equal bilaterally. Sluggish responses and differences in diameter greater than 1 mm must be attributed to intracranial injury and should result in further diagnostics.

Table 11 Glasgow Coma Scale and Pediatric Glasgow Coma Scale

Parameter	Response (four years of age and older)	Response (less than four years of age)	Score
Eye opening	Spontaneous	Spontaneous	4
	To verbal command	React to voice	3
	To pain	React to pain	2
	Unresponsive	Unresponsive	1
Verbal response	Oriented	Smiles, follows objects, interacts	5
	Disorientated	Cries but consolable, inappropriate	4
	Inappropriate words	Inconsistently consolable, moans	3
	Incomprehensible sounds	Inconsolable, irritable	2
	Unresponsive	Unresponsive	1
Motor response	Obeys commands	Spontaneous, obeys commands	6
	Localizes pain	Localizes pain	5
	Withdraws to pain	Withdraws to pain	4
	Flexion to pain	Flexion to pain	3
	Extension to pain	Extension to pain	2
	Unresponsive	Unresponsive	1

The unilaterally dilated pupil usually indicates a third cranial nerve palsy due to transtentorial herniation. Anisocoria can also exist congenitally, following cataract surgery, due to ophthalmoplegia or rarely due to a unilateral administration of mydriatic eye drops. However, until proven otherwise anisocoria should be assumed to result from increased ICP. **In 94% of adult TBI patients, the dilated pupil occurs on the side of an intracerebral mass lesion.** Patients presenting this sign require urgent diagnostic evaluation (CT scan) and frequently immediate intervention. Various drugs, mainly atropine and opioids, can also alter pupil size and reaction. In addition to these and obvious ocular or vitreal–retinal injuries, papillary asymmetry as well as areflexia may also be caused by injuries to the optic nerve associated with basilar skull fractures.

Motor Examination

The primary test to assess motor function is to watch gross motor movements of the patient's fingers and toes. This can best be achieved by asking the patient to move extremities or wiggle digits. Comparing the differences between right and left sides can reveal extremity weakness. Any lateralized weakness suggests a pathological condition. Signs of lateralization may include a delayed response to stimuli, the need for a greater stimulus, or reduced muscular strength. **Muscle weakness occurs contralateral to the intracerebral mass lesion in approximately 75% of adult TBI patients.** A more complete and time-consuming examination of muscle strength, tone, and symmetry will be performed during the SS in stabilized patients.

Cervical spine injury is suspected in any patient suffering from whiplash injury to the cervical spine and serious head or maxillofacial trauma. The leading symptom of any vertebral spine injury is localized pain, paresis, and paralysis which indicate that the spinal cord is also injured (thus the "three Ps"). Other symptoms vary, depending on location of injury and extent of spinal cord damage (Table 12). Clinical examination may reveal swelling or deformities in the back of the neck, but radiographic evaluation is required to stage these injuries.

Injury to the sympathetic pathways results in spinal shock in patients with thoracic and cervical spine lesions. Such patients show typical signs of hypotension, usually in conjunction with bradycardia.

Sensory Function and Other Symptoms

A sensory deficit should be diagnosed as early as possible to prevent any further compromise during patient positioning and transport. Loss of all sensation below a specific vertebral level suggests an SCI. Loss of sensation relegated to one side of the body correlates with a high central nervous system lesion before entering the brainstem structures.

Table 12 Symptoms of Spinal Cord Injuries

Pain at the injury site
Paresis below the level of injury
Paralysis below the level of injury
Paresthesia
Loss of sensation and reflexes below the level of injury
Impairment of ventilation (high-level lesion of the C-spine)

Abbreviation: C-spine, cervical spine.

Other signs and symptoms of potential neurological damage include increased severity of headache or development of nausea and vomiting.

EXPOSURE/ENVIRONMENTAL CONTROL

Exposure

The patient should be completely undressed. When patients arrive in obviously expensive clothing and are awake and cooperative, then pants or skirts can often be removed without damaging the garments while still maintaining axial spine precautions. These awake patients should be kept covered immediately following exams or procedures to preserve warmth and to provide some degree of privacy and modesty. However, patients who are unstable must have their clothes removed by cutting with "trauma shears" as fast as is safely possible to gain access, and thus control hemorrhage, place IV catheters, and fully evaluate all injuries and all body surfaces. The cutting must be done carefully to avoid injury or inadvertently severing IV lines that were started in the prehospital environment. The patient should be surveyed from head to toe, front and back, including axillae and perineum.

Environmental Control

After removing all the garments, the patient must be re-covered with warm blankets or sheets to prevent hypothermia in the ED. External warming devices such as overhead warming lights can also be employed. Hypothermia (Volume 1, Chapter 40) adds additional morbidity to the trauma patient mainly through the associated coagulopathy. Watts et al. (74) showed that patients whose temperature was $\leq 34^{\circ}C$ demonstrated significant coagulopathy. Others have shown that hypothermia occurs commonly in severely injured patients and is associated with a high mortality rate (75).

Intravenous fluid should be warm. Fluid at a room temperature of 18°C or, even worse, cold blood from the blood bank with a temperature of 4°C will cause hypothermia in the injured patient. When large flow rates are required, a high-volume and heat capacity fluid warmer should be used. There are several technologies available on the market (see Volume 1, Chapters 5 and 10).

EYE TO THE FUTURE

Appropriate and effective airway management is fundamental to treating trauma patients. In most settings, the airway can be successfully managed by experienced personnel as described here and in Volume 1, Chapter 9. Training prehospital providers as well as trauma resuscitation hospital personnel in management techniques for difficult airways should further improve outcomes. Because many anesthesiologists and emergency medicine physicians work in settings with minimal trauma, they should regularly enroll in practical courses that teach the use of the LMA, ETC, TTJV, and cricothyroidectomy, so they can be prepared for emergency trauma airways when they arrive. Additionally, mastery of the use of the FOB for intubation, verification of tube position, and diagnosis is becoming mandatory. Verification of ETT position with $ETCO_2$ and/or EDD is now a required standard (and should be documented).

Chest tubes should be placed on the basis of clinical examination indicating tension pneumothorax or hemothorax. However, increasingly, trauma surgeons are finding that the FAST examination can be used to diagnose pneumothorax and/or hemothorax (76). This evolving technique expands the use of ultrasound beyond detecting abdominal and pericardial blood to obtain a rapid diagnosis of hemo-pneumothorax.

The type and the quantity of fluid that should be administered during initial resuscitation is an important question that has yet to be answered. Ongoing research also continues in the use of "artificial blood" products (see Volume 2, Chapter 59) (77,78). The potential decreased need for blood-typing, and the decreased risk of immunosuppression and infection, as well as the extended shelf-life makes artificial blood an important area of future research pertinent to the early resuscitation occurring during the PS.

Transport of unstable patients to the CT suite is time-consuming and dangerous. Outfitting CT scanning machines in the trauma resuscitation suite is an expected future trend. It is further anticipated that increasing numbers of patients will soon receive "total body CT scans" upon admission to the resuscitation bay, further expediting treatment and increasing accuracy of diagnosis. In that event, the CT scan can be performed simultaneous with resuscitation and may become an integral part of the PS rather than its current relegation to the SS. To a certain extent, this is already being done in some Israeli centers and at the Shock Trauma Center of the University of Maryland.

A more rapid evaluation of coagulation status may be useful in certain patient populations (e.g., those with known TBI, hypothermia, and jaundice or elderly). Use of a rapid activated clotting time (ACT) assay in these patients may help define those at high risk and trigger early use of FFP or factor VIIa.

Although hypothermia is known to cause coagulation problems, moderate hypothermia leads to improvement in outcome in brain injuries (79). Ongoing research focuses on novel techniques to maintain moderate hypothermia without a negative effect on coagulation, especially in TBI patients.

SUMMARY

The ABCDE approach to the PS provides an optimal system whereby life-threatening problems involving the most critical systems (airway, breathing, circulation, and disability) are diagnosed and treated first. Next, the patient is exposed so that all body surfaces are inspected in search of occult injuries. Once all life-threatening conditions are diagnosed and treated, the SS commences (Volume 1, Chapter 14). Resuscitation continues during both the PS and the SS, and constant re-evaluation of the ABCDs is required for optimum management. In severely injured patients, the PS and SS may occur in the OR, and certain elements of the SS (e.g., definitive imaging of extremities and the axial spine) may be deferred until after life-saving maneuvers are completed (e.g., immediate splenectomy in an exsanguinating patient). Each of the elements in the PS is discussed in greater detail in subsequent chapters.

KEY POINTS

- The PS is performed in a prescribed sequence, which reviews the most life-threatening conditions first including evaluation of airway, breathing, circulation, disability, and exposure (ABCDEs) (Table 1).
- Assessment of airway patency and spontaneous breathing is the crucial first step, which should be completed within the initial 10 to 15 seconds of the PS.
- Cervical spine immobilization should be maintained until neck injuries are ruled out.
- Cricoid pressure should be maintained until the tracheal tube cuff is inflated and correct positioning of the ETT is confirmed.
- Direct laryngoscopy with orotracheal intubation is the principal method used in acute trauma patients because of speed and technical advantages.
- Assisted ventilation (i.e., "modified RSI") is frequently justified because trauma patients are often hypoxemic and hypercapneic.
- All patients should receive 100% oxygen by the facemask or via the BVM ventilation device for a full five minutes or with four to eight vital capacity breaths prior to initiating RSI.
- Following intubation, the tube position must be confirmed with measurement of end-tidal CO_2 ($P_{ET}CO_2$) or by use of an esophageal detector device (EDD) in conjunction with clinical signs.
- Distended neck veins are a sign of increased intrathoracic pressure, as occurs with a tension pneumothorax, massive hemothorax, or cardiac tamponade.
- Tension pneumothorax, massive hemothorax, and cardiac tamponade should be clinically diagnosed and treated prior to CXR.
- Whenever a needle thoracostomy is used, it must be followed up by placement of a chest tube.
- If more than 1500 mL of blood is evacuated after the initial chest tube placement, or drainage of more than 200 mL/hr persists for two to four hours, consideration should be given to operative exploration (26).
- "Needle pericardiocentesis" is only a temporizing procedure. After relieving the tamponade, the catheter should remain in the pericardial sac (for further drainage) and the patient should then be transported to the OR for a definitive treatment.
- When choosing a ventilator for trauma patients in the resuscitation suite, reliability, mobility, and simplicity are the most important characteristics.
- Hemorrhage is considered as the primary source of hemodynamic instability in trauma patients until proven otherwise.
- Raised HR infers diminished intravascular volume, but is modified by vagal tone, emotional stress, pain, and drugs.
- Hypotension is the most common indication of circulatory dysfunction. Nevertheless, normal BP does not exclude circulatory impairment following trauma, as 30% of the blood volume may be lost before hypotension begins to occur.
- Hypothermia can modify circulatory response to trauma.
- Urine output is an important but not an immediate indicator of intravascular volume and systemic perfusion.
- Injury to the spinal cord will exacerbate any hemorrhage-induced hypotension because the normal sympathetic compensation to hypovolemia is lost.
- The conventional resuscitation approach presently favors maintaining BP and tissue perfusion until blood loss is controlled with fluid resuscitation to avoid lactic acidosis and organ failure.

- Trauma patients with uncontrolled hemorrhagic shock require damage control surgery without time delay.
- Normal Hgb levels do not assure that the patient has not sustained significant blood loss.
- Analysis of the ABG (which measures pH, P_aO_2, P_aCO_2, and bicarbonate) provides information on the oxygenation, ventilation, and metabolic status of the patient.
- Traditionally, an elevated blood lactate level after hemorrhage is interpreted as tissue hypoperfusion, hypoxia, and anaerobic glycolysis.
- The FAST examination is noninvasive, more rapid, and less expensive than DPL, but can also miss some injuries.
- Hemodynamically unstable patients should go to the OR rather than the CT scanner.
- A useful mnemonic for obtaining a rapid history is AMPLE: allergies, medications, past medical history, last ate/drank, events leading up to the incident.
- The GCS, developed in 1974, is the most widely used system for level of consciousness assessment in trauma.
- In 94% of adult TBI patients, the dilated pupil occurs on the side of an intracerebral mass lesion.
- Muscle weakness occurs contralateral to the intracerebral mass lesion in approximately 75% of adult TBI patients.

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9

Definitive Airway Management

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INTRODUCTION

Airway loss is a major cause of preventable prehospital deaths (1). Trauma airway management is complicated due to associated pathology, suboptimal intubating conditions, and because full preintubation evaluation and planning is rarely possible. Furthermore, trauma patients are at increased risk for hypoxia, airway obstruction, hypoventilation, hypotension, and aspiration. Optimum management of the trauma airway requires proper evaluation, preparation, and expeditious execution with readily available backup rescue options (i.e., plan "B").

Airway management disasters account for a large proportion of malpractice claims in the American Society of Anesthesiologists (ASA) closed claims database. A statistically significant reduction in airway management claims has occurred over the last decade because of the introduction of the ASA difficult airway (DA) algorithm, which institutionalized the need for airway evaluation, awake intubation techniques, and the use of back-up rescue modalities [e.g., laryngeal mask airway (LMA), esophageal-tracheal-combitube (ETC), and transtracheal jet ventilation (TTJV)] (2). The authors believe that incorporation of the ASA DA algorithm (with certain minor modifications) can likewise improve safety in trauma airway management.

This review of definitive airway management for trauma and critical care begins with a survey of the equipment and drugs that should be prepared ahead of time, defines and characterizes the "DA," algorithm and describes the principles of airway evaluation under both elective and emergency trauma conditions. The essential elements of conventional trauma airway management are then provided, followed by a review of the principles and techniques that should be considered when managing the difficult trauma airway. Emphasis is placed throughout the chapter on proper evaluation and prioritization of treatment, with awake intubation techniques recommended for DA management of cooperative and stable trauma patients. The authors also recognize that emergency airway adjuncts (e.g., LMA, ETC, TTJV, etc.) may be required to rescue the cannot intubate–cannot ventilate (CNI–CNV) situation. Specific tips are provided regarding successful techniques and pitfalls of fiberoptic bronchoscopy (FOB) in a dedicated section, and this technique is appropriately emphasized throughout this chapter.

After providing a survey of the major considerations and tools useful in trauma airway management, the ASA DA algorithm is formally reviewed along with the suggested modifications required for trauma situations. With this foundation, the management of five common trauma DA scenarios are reviewed. Important trauma airway complications are then summarized. Finally, new concepts and techniques that are currently being developed to improve trauma airway management are described in the "Eye to the Future" section.

EQUIPMENT AND DRUG PREPARATION

Regardless of the urgency associated with any particular intubation event, several key drugs and airway management tools are universally required; these should be available (and guaranteed to be in working order) before being called to care for a trauma patient. The critical emergency airway equipment items are listed in Table 1, and include: (*i*) an oxygen (O_2) source and various types of administration devices; (*ii*) an assortment of oral and nasal airways, along with a bag-valve-mask (BVM) ventilation device capable of applying positive pressure ventilation (PPV) (and able to deliver 100% O_2); (*iii*) intubation equipment [including laryngoscopes, styletted and pretested endotracheal tubes (ETTs)]; (*iv*) suction tubing and a tonsil-tipped suction device; (*v*) a functioning intravenous (IV) catheter; (*vi*) prelabeled syringes containing induction and resuscitation drugs (including vasopressors and inotropes); (*vii*) appropriate monitors and intubation detectors (as will be described below). All of the aforementioned equipment (except for the O_2 source) should fit into a portable storage unit (i.e., "Code Bag") for trauma resuscitation. In austere environments, small tanks of O_2 will also need to be transported to the site of emergency airway management. The importance of each of these essential airway management devices and drugs will be reviewed in this section.

Oxygen: Critical During Trauma Airway Management

Advanced Trauma Life Support® (ATLS®) begins with assessment and management of the airway and breathing, the top

Table 1 Emergency Airway Equipment Contained in Portable Storage Unit for Trauma Resuscitation

Requirement	Equipment
Oxygen	BVM with oxygen inflow tubing
Ventilation	Soft nasal airway
	Rigid oral airway
	Emergency cricothyroidotomy device, [or TTJV equipment]
Intubation	Laryngoscope with new tested batteries
	#3 and #4 Macintosh blades with functioning light bulbs
	#2 and #3 Miller blades with functioning light bulbs
	ETTs—various sizes styletted with balloon tested
	LMA or ETC
	Tracheal tube guides (semi-rigid stylets, ventilating tube changer, light wand)
	[Flexible fiberoptic intubation equipment
	Retrograde intubation equipment]
	Adhesive tape or umbilical tape for securing ETT
Suction	Yankauer, endotracheal suction
Monitor	CO_2 detector, EDD
Drugs	IV induction and paralytic medication
	[Topicalization drugs
	deVilbiss sprayer for application of topical drugs]
	Resuscitation drugs (epinephrine, atropine, etc.)
Miscellaneous	Various syringes, needles, stopcocks, IV connector tubes

Note: More equipment = less portability, items in brackets [ ] are less mandatory.
Abbreviations: BVM, bag-valve-mask; EDD, esophageal detector device; ETC, esophageal-tracheal-combitube; ETTs, endotracheal tubes; IV, intravenous; LMA, laryngeal mask airway; TTJV, transtracheal jet ventilation.

two priorities in the airway, breathing, circulation, disability, and exposures (ABCDEs) of the primary survey (reviewed in Chapter 8). **As soon as a trauma patient is encountered in the field or in the trauma resuscitation suite (TRS), O_2 is immediately applied. Furthermore, O_2 should be administered throughout the trauma assessment and treatment phase.**

Numerous causes of hypoxemia exist and all are improved with the administration of 100% O_2 (Table 2). Hypoxemia is a constant threat in trauma and critical illness due to disease processes that cause respiratory failure and those associated with injury. In addition, 100% O_2 should be administered for three to five minutes immediately preceding airway management (i.e., "preoxygenation") to increase the duration of adequate O_2 saturation during the period of postinduction apnea.

Treatment of Hypoxemia

Hypoxia is defined as decreased O_2 tension at any location inside or outside the body. Clinically, the term hypoxia denotes decreased O_2 tension at the tissue level. Hypoxemia is defined as decreased O_2 tension in the arterial blood (PaO_2). In trauma scenarios, when tissue hypoxia occurs, hypoxemia is nearly always present.

There are eight major causes of hypoxemia (Table 2). The first five etiologies are related to the atmosphere [low partial pressure of inspired O_2 (PIO_2)] or the lungs [hypoventilation, ventilation-perfusion ($\dot{V}/\dot{Q}$) mismatch, right-to-left transpulmonary shunt ($\dot{Q}_s/\dot{Q}_t$), and diffusion abnormalities]. The next two causes of hypoxemia involve delivery of O_2 ($\dot{D}\,O_2$) to the tissues [i.e., low oxy-hemoglobin or low cardiac output ($\dot{Q}$)]. The final cause of hypoxemia is termed "histocytic," denoting a problem in O_2 utilization at the tissue level, usually because of the poisoning of the mitochondrial electron transport chain, as seen with cyanide or carbon monoxide toxicity. Patients suffering from all of these eight causes of hypoxemia will benefit from the administration of 100% O_2 (these topics are further developed in Volume 2, Chapters 2 and 23).

Preoxygenation: Maximizing PaO_2 During Apnea

During trauma airway management, O_2 is administered prior to intubation in a process known as preoxygenation. **Optimum preoxygenation requires that 100% O_2 be delivered by a tight fitting mask during spontaneous ventilation (SV) for three to five minutes prior to administering drugs that cause apnea.** If the time does not allow for a full five minutes of preoxygenation, the patient should be instructed to take four to eight vital capacity breaths; this will increase O_2 stores, though not to the same level as a full five minutes of preoxygenation. The goal of preoxygenation is the replacement of nitrogen with O_2 (de-nitrogenation), thereby increasing the O_2 stores in the lungs, arterial, and mixed venous blood, as well as in the tissues. Consequently, the duration that apnea can be endured without causing arterial desaturation of O_2 is prolonged.

Preoxygenation of the lungs is an essential component of any intubation technique that might involve a period of apnea. Preoxygenation is especially important for a rapid sequence intubation (RSI). When a patient is rendered apneic, the patient has a finite period of time prior to arterial desaturation. This time period is directly related to the reservoir of oxygen in the lungs at end-exhalation during normal tidal breathing [the functional residual capacity (FRC)], and inversely related to the oxygen consumption ($\dot{V}O_2$—approximately 250 mL/min in 70 kg patient) (Fig. 1).

Preoxygenation with 100% O_2 allows for up to 10 minutes of oxygen reserve following apnea in a normal patient at rest with healthy lungs and a normal FRC ($\sim$2.5 L). However, the same patient when breathing room air (21% O_2) would have about one-fifth the time (only two minutes) prior to arterial desaturation. Furthermore, trauma patients frequently have a decreased FRC due to

Table 2 Causes of Hypoxemia in Trauma and Critically Ill Patients Requiring Emergency Airway Management

Causes	Example	$P(A\text{-}a)O_2$	$PaCO_2$	Response to 100% O_2[a]	Therapy
Environmental causes (low PIO_2)	Low P_B (altitude) Low FIO_2 (e.g., excess N_2O)	Normal Normal	Normal Normal	↑ P_aO_2 ↑↑ P_aO_2	Give O_2 Give O_2
Hypoventilation	Flail chest Heroin OD SCI	Normal	↑↑	↑ P_aO_2	Give O_2 then ↑ V_A
$\dot{V}_A/\dot{Q}_t$ mismatch	Hypovolemia Excessive V_T Excessive PEEP	↑↑	Normal	↑↑ P_aO_2	Give O_2 then ↑ intravascular volume and adjust ventilation
Shunt ($\dot{Q}_s/\dot{Q}_t$) R → L trans-pulmonary shunt	Lung collapse (PTX, HTX, atelectasis) Pneumonia (aspiration) Pulmonary contusion Fat embolus TRALI ARDS (Sepsis/SIRS)	↑↑	Normal	No improvement in Q_s/Q_t units, but never all 2° to shunt	Give O_2 then add PEEP, ↑ I:E ratio as tolerated
Diffusion	Massive fluid resuscitation (interstitial edema) ARDS	↑↑	Normal	↑ P_aO_2	Give O_2 then ↑ PEEP, diurese when clinically applicable
Anemia	Hemorrhage	↑	Normal	↑ P_aO_2 (↑ O_2 content)	Give O_2 then transfuse PRBCs
↓ $\dot{Q}$	Hypovolemia Myocardial Ischemia Cardiac Tamponade PTX/HTX	↑↑	May ↓ in response to metabolic acidosis	↑ P_aO_2 (↑ O_2 content)	Give O_2 then treat 1° cause
Histocytic hypoxic conditions	CN toxicity CO toxicity	↑↑	May ↓ initially then ↑ as respiratory failure occurs	↑ P_aO_2	Give O_2 then add HBO for CO poisoning and d/c SNP for CN^- toxicity

[a]Compared with $FIO_2 = 0.21$.

Abbreviations: ↑, increased; ↓, decreased; ARDS, acute respiratory distress syndrome; Asp, aspiration; CN, cyanide; CNI/CNV, cannot intubate/cannot ventilate situation; CO, carbon monoxide; FIO_2, fraction of inspired oxygen; HBO, hyperbaric oxygen; HTX, hemothorax; N_2O, nitrous oxide; OD, overdose; P_B, barometric pressure; $P(A\text{-}a)O_2$, partial pressure difference in O_2 between the alveolus (A) and arterial blood (a); P_aCO_2, partial pressure of CO_2 in arterial blood; PEEP, positive end expiratory pressure; PIO_2 (partial pressure of inspired O_2), $FIO_2 \times P_B$; $\dot{Q}$ = cardiac output; PRBCs, packed red blood cells; PTX, pneumothorax; SCI, spinal cord injury; SNP, sodium nitroprosside; TRALI, transfusion related acute lung injury; V_A, alveolar ventilation; V_A/Q_t mismatch, alveolar ventilation/perfusion mismatch; V_T, tidal volume.

numerous causes (e.g., pneumothorax, hemothorax, rib fractures, diaphragmatic hernia, abdominal injuries including intra-abdominal blood, etc.) and will desaturate earlier than normal following apnea. Patients in respiratory failure (i.e., cardiogenic or noncardiogenic pulmonary edema, pneumonia, or pulmonary contusion) will desaturate even sooner because of increased O_2 consumption, increased right-to-left transpulmonary shunting and further decreased FRC (atelectasis, lobar collapse, see Fig. 2), (4).

Ventilation and Intubation Equipment

An assortment of facemasks should be available, as discussed below, and one should be attached to the BVM ventilation device. This should be pretested for integrity and ability to generate positive pressure without leaks at various connections, and should be capable of delivering 100% O_2 at high flow rates. In austere environments, where O_2 supplies are intermittent, a self-inflating BVM device such as an AMBU® bag is recommended.

Rigid oral and soft nasal airways should be available in small, medium, and large sizes for the adult patient. To manage pediatric airways, a pediatric kit with appropriate sized equipment must also be available.

Various sized, styletted ETTs, with pretested balloons, should be prepared as follows. An adult-sized ETT (size 7.0 or 8.0) should have a malleable stylet passed through its interior to a position just short (5–10 mm) of the tip. The malleable stylet allows the distal end of the ETT to be molded into a configuration that will most easily pass through the patient's vocal cords. In addition, a styletted 6.0 ETT (or 5.0 ETT) should be prepared as a backup for patients who have small glottic openings and/or DAs (smaller ETTs more easily pass through swollen or edematous glottic openings and into the trachea).

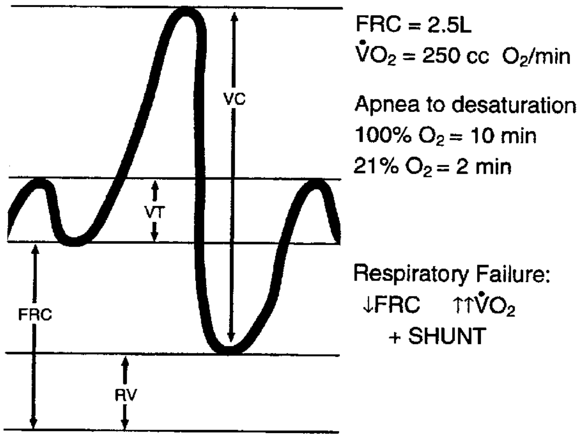

Figure 1 Functional residual capacity (FRC) and relationship of oxygen reserve. This figure illustrates the factors that determine the time from apnea until desaturation including the FRC, the concentration of oxygen in this reservoir (FIO_2), and the oxygen consumption ($\dot{V}O_2$) of the patient. The spirometric trace on the left side of the figure depicts the relative volumes of the FRC, tidal volume, residual volume, and vital capacity. The reservoir of oxygen in the lungs at end-exhalation (FRC) in a normal 70 kg patient is approximately 2.5 L, and the resting $\dot{V}O_2$ is approximately 250 cc/min. If the patient is breathing 100% oxygen then there is theoretically 10 minutes prior to desaturation. Whereas, if the patient is breathing room air (21% oxygen) there is only two minutes prior to desaturation. Furthermore, intensive care unit patients are typically sicker with lower FRCs, increased $\dot{V}O_2$, and increased shunting, all of which can cause more rapid desaturation following apnea. *Abbreviations*: FRC, functional residual capacity; RV, residual volume; VC, vital capacity; VT, tidal volume. *Source*: From Ref. 7.

The rigid direct laryngoscope (RDL), with several blades, is the central piece of intubation equipment. The RDL handle should be clean and all electrical connections must be free of any corrosion or debris. The batteries should be fully charged, and one should verify that a bright beam of light is generated when the RDL blade is attached and extended into the working position. The authors recommend that at least two sizes of Miller (#2 and #3) and two sizes of Macintosh blades (#3 and #4) be provided in the kit, as each one has advantages in certain types of airway problems. All of the items listed in Table 1 are essential and constitute the minimum airway equipment that should be contained in the "code bag" (a.k.a. portable storage unit).

Suction Equipment

Trauma patients, like others in respiratory failure, can have thick, tenacious, or bloody secretions and may have regurgitated. In order to minimize the risk of aspiration and to better visualize equipment the laryngeal anatomy, suctioning of the airway is frequently required during a trauma intubation.

The suction apparatus should provide a continuous vacuum of sufficient force to rapidly clear the thick oropharyngeal secretions or vomitus. During initial airway management, a large tonsil type suction tip (e.g., Yankauer®) should also be used to aspirate debris out of the oropharynx. After tracheal intubation, long soft endotracheal suction catheters should be available to clear tracheo-bronchial secretions as well as any aspirated material from the

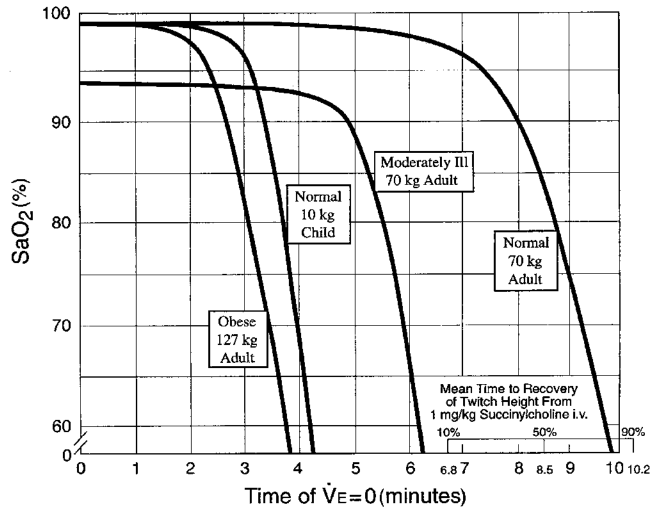

Figure 2 SaO_2 versus time of apnea for various types of patients. Time to hemoglobin desaturation with initial $F_iO_2 = 0.87$. The physiologic characteristics of these patients can be obtained from the author upon request. The SaO_2 versus time curves were produced by the computer apnea model. The mean times to recovery from 1 mg/kg intravenous succinylcholine are shown in the lower right hand corner. *Source*: From Ref. 4.

airways. Alternatively, an FOB can be used, postintubation, to remove plugs and secretions from specific lung segments under direct vision. The FOB can also be used to diagnose existing airway pathology and confirm ETT position. Small, portable, battery-powered FOB devices are now available, and should be contained in the Trauma Code bag.

Functioning Intravenous Catheter

A functioning IV catheter is another mandatory component of preintubation preparation, especially when airway control is urgent–emergent but the patient has not yet arrested. The ability to administer fluids, cardiovascular support drugs and other medications is obviously essential. Thus, after applying O_2 by mask, assessing the airway and ensuring ventilation, an IV should be established (i.e., "C" in the ABCDEs of the primary survey) prior to attempting any airway manipulation to support the circulation, whenever time allows. If confronted with a patient in full arrest, the trachea should be intubated first and IV access secured immediately after initiating CPR, performing cardioversion, or implementing a resuscitative thoracotomy (Volume 1, Chapter 13).

It is noteworthy to recognize that all Advanced Cardiac Life Support® (ACLS®) protocol drugs can be administered via the ETT except for high concentration ionic compounds (e.g., calcium, bicarbonate, magnesium, etc.). Two large bore peripheral IVs are preferred. If access cannot be immediately obtained, a central venous catheter should be placed [preferably a large bore, i.e., 9 Fr, introducer (see Volume 1, Chapter 10).

Monitoring and Endotracheal Tube Confirmation Devices

Pulse oximetry, blood pressure (BP), and continuous electrocardiogram (ECG) constitute the appropriate minimal noninvasive monitoring that should be applied prior to attempting tracheal intubation. Naturally, a complete set of vital signs, including respiratory rate and temperature, are also obtained when time allows. Vital sign stability and adequate arterial oxygen saturation (SaO_2) are the goals prior to, during, and after intubation of the trachea. Immediately following a putative endotracheal intubation, the partial pressure of CO_2 at the end of the exhaled breath ($P_{ET}CO_2$) should be monitored. A number of devices and techniques for measuring $P_{ET}CO_2$ are available, and can be used to confirm ETT position and subsequently to assess ongoing ventilation adequacy. In situations with low or no cardiac output, an esophageal detector device (EDD) is used to confirm endotracheal tube position. Both of these items should be contained in the portable storage unit (Table 1); their functions (as well as advantages and disadvantages) will be further discussed in detail subsequently.

Vasopressors and Inotropes

Vasopressors must be available for immediate use because hypotension is a frequent accompaniment of trauma and critical illness. In addition, the administration of anesthetic drugs and the use of PPV can exacerbate or initiate hypotension in hypovolemic patients. Furthermore, premorbid conditions in previously ill or elderly patients will further increase the likelihood of hypotension following intubation (discussed further subsequently).

Portable Storage Unit for Trauma Resuscitation

Underscoring the importance of adequate preparation, the authors endorse the 2003 ASA DA Guidelines recommending the use of a portable storage unit (a.k.a. "Code Bag") containing the above prescribed airway and resuscitation equipment (Table 1) (3). Commercially available toolboxes or soft duffel bags can be used for this purpose, in addition to the aforementioned items, as well as the adjunct equipment needed for assistance in managing the "difficult trauma airway." Each portable storage unit should be customized to meet the specific needs and preferences of the practitioner as well as the health care facility, and it should be stored in the TRS (or brought there by the airway expert) (3).

DEFINITION OF THE DIFFICULT AIRWAY

Airway difficulty can occur during BVM ventilation or during endotracheal intubation. Both are not synonymous; indeed, some patients who feel difficult to ventilate using a BVM device (e.g., edentulous, large jaw) may feel quite easy to intubate. The difficulty of maintaining gas exchange using BVM ventilation can range from zero degree of difficulty to infinite (Fig. 3).

Difficulty of intubation using direct laryngoscopy also proceeds along a similar continuum from easy to nearly impossible (Fig. 3). Difficult intubation has been defined as requiring multiple attempts with multiple maneuvers including external laryngeal manipulation, multiple laryngoscope blades, and/or multiple endoscopists (5). Most recently, the ASA DA Guidelines has defined difficult laryngoscopy as the impossibility of visualizing any portion of the vocal cords after multiple attempts using a conventional RDL (3).

Probably the best definition of difficult intubation for documentation (from one anesthesiologist to another) and for research purposes involves the grading of the laryngoscopic views as defined by Cormack and Lehane (6). In the Cormak and Lahane's classification (Fig. 4), Grade I denotes visualization of the entire laryngeal aperture; Grade IV is visualization of only soft palate; Grades II and III

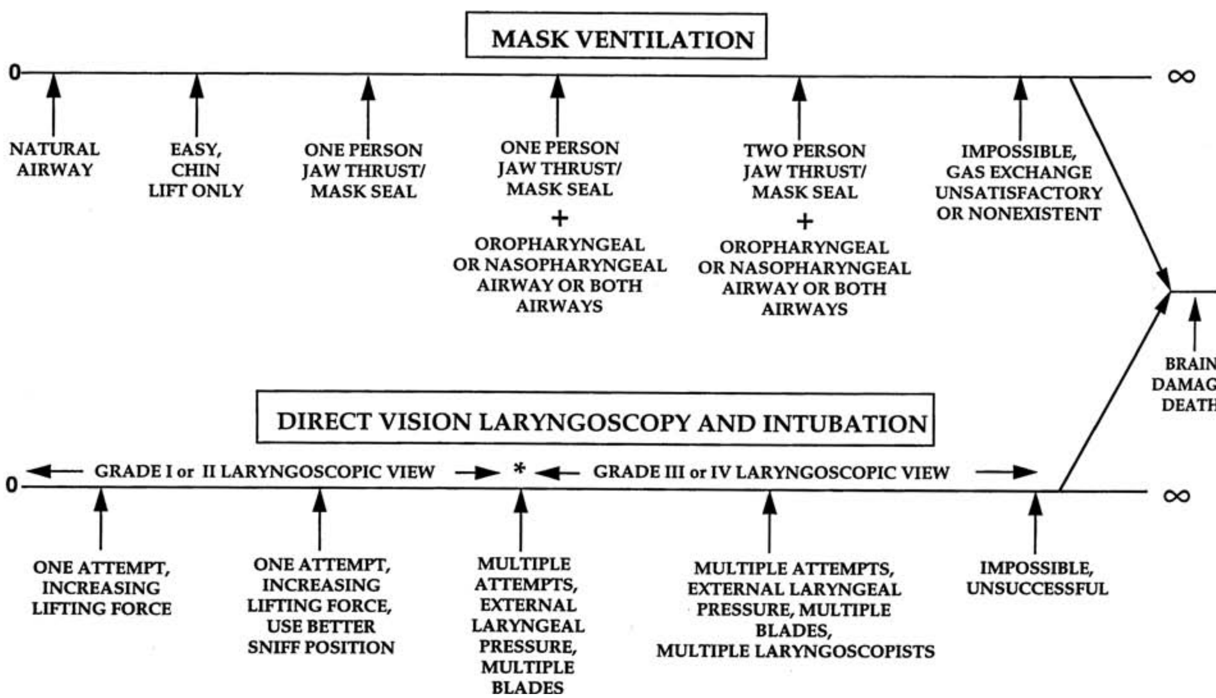

Figure 3 Degree of airway difficulty continuum for mask ventilation and direct vision laryngoscopy at intubation. This illustration serves to provide a conceptual framework for the definition of airway difficulty with mask ventilation (*top*) and direct vision laryngoscopy (*bottom*). The degree of difficulty ranges from 0° of difficulty to the impossible or infinitely difficult airway. The amount of difficulty can vary in the same patient with different anesthesiologists using various techniques. The grade of laryngoscopic view refers to grades defined by Cormack and Lehane (Fig. 4). *Source*: From Ref. 3.

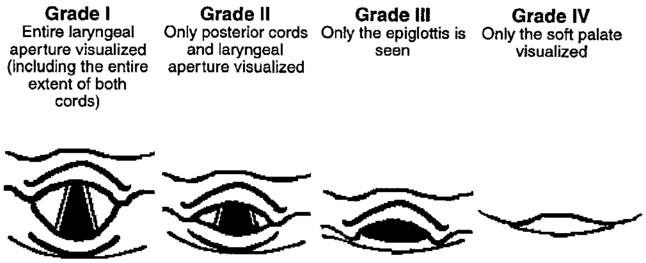

Figure 4 Four grades of laryngoscopic view. The grading of laryngoscopic view is based upon the anatomic features that are visualized during the performance of direct laryngoscopy. *Source*: From Ref. 6.

are intermediate views (7). Grade III or IV laryngoscopic views correlate well with difficult intubations in the vast majority of patients (8,9). However, there are some clinically relevant situations that provide exceptions to this rule. First, the skill and experience of the endoscopist in manipulating the RDL, the ETT, and the patient's anatomy must be taken into account. Secondly, a Grade III laryngoscopic view has been described differently by different investigators (8,10). Thirdly, the blade attached to the RDL will affect the laryngeal view and therefore the assigned grade. Fourthly, the blade selection can solve (or exacerbate) certain problems. For example, a long floppy epiglottis may yield a high-grade view (III, IV) with a Macintosh blade and a relatively low-grade view (I, II) if a straight blade were used. Finally, traumatic conditions such as cervical spine (C-spine) injury (i.e., inability to move the neck into a "sniffing position"), laryngeal fractures, or expanding hematomas may disassociate the laryngoscopic view from the difficulty of tracheal intubation. Despite these considerations, the laryngoscopic grading of Cormack and Lahane is used by most authors to define intubation difficulty and should be documented for each patient intubated (6).

Historical Indicators of Airway Difficulty

The intent of obtaining an airway history is to elicit previously known factors indicating that airway management has been (and likely will be) difficult. Any patient who is awake and capable of coherent conversation should be asked about prior intubation and ventilation successes or failures. Some patients possess a Medic Alert bracelet indicating a history of difficult intubation or ventilation and this can be useful in obtunded patients. Frequently, trauma patients requiring emergent airway management are disoriented and unable to contribute historical data. Regardless of the patient's mental state, if time permits, the physician should review the patient's chart for details of previous intubations (easy or difficult), and other concurrent problems that may complicate intubation (e.g., likely C-spine injury). If an obese patient requires nasal continuous positive airway pressure (CPAP) at night to sleep, this may indicate that mask ventilation and/or intubation will be more difficult than in a thin patient without such history.

Pathologic/Anatomic Predictors of Airway Difficulty

In the trauma setting, numerous lesions (hematoma, foreign body, and facial fractures/edema) can pose difficulty for SV as well as BVM ventilation and intubation (Table 3). Suspected C-spine injuries pose intubation difficulty because of inability to extend the head on the neck or flex the neck

Table 3 Anatomic/Pathologic Predictors of Difficult Intubation/Ventilation

Anatomy	Difficult ventilation	Difficult intubation
Neck	Bull neck	Bull neck
	Obesity	Obesity
		Decreased head extension or neck flexion
Tongue	Large tongue	Large tongue
Mandible	Thick beard	Receding mandible
		Decreased jaw movement
Teeth	Edentulousness	Buck teeth
Pathology		
Maxillofacial	Facial fractures and lacerations	Facial fractures
	Facial plethora	Facial plethora
Oropharyngeal	Edema	Edema
	Hematoma	Hematoma
	Inflammation	Inflammation
	Foreign body	
	Tumor	
Glottis	Edema	Edema
	Vocal cord paralysis	Vocal cord paralysis
Neck	Penetrating injury	C-spine injury
	Subcutaneous emphysema	Cervical mass/hematoma
		Subcutaneous emphysema

on the chest (discussed in detail subsequently). Other trauma conditions that make intubation difficult include burns and other inflammatory conditions where massive edema can impair laryngoscopic view. Similarly, stab wounds or blunt trauma to the soft tissue in the neck can cause expanding hematomas or airway disruption to occur. These and other trauma DA scenarios are discussed in detail subsequently.

Anatomic predictors of difficult mask ventilation and subsequent intubation may be evident before formal examination (Table 3). Morbid obesity poses difficulty with mask ventilation because of inadequate mask fit and difficulty in holding the mask to the massive face using only one hand. In addition, ventilatory efforts are more difficult because of the decreased compliance of the chest wall. Obese patients are further problematic because of the decreased FRC and propensity for rapid desaturation. Furthermore, soft tissues in the obese patient can intrude on the airway above (and occasionally below) the glottis, further impeding ventilation. Another common mask ventilation problem is the case of sunken cheeks and edentulousness where the mask fit and subsequent ventilation can be very difficult; interestingly, intubation of edentulous patients is typically easy.

Whenever intubation or ventilation difficulty is expected, the airway practitioner should ask for experienced help prior to the initiation of treatment. In addition, whenever the patient is recognized to have a DA, the clinician should consider securing the airway awake. In trauma patients who are uncooperative or hemodynamically unstable, an awake technique may not be possible (alternate options are discussed in detail subsequently) (11). But first, the specific endpoints of airway examination are reviewed.

AIRWAY EXAMINATION PRINCIPLES

The 11-Step Airway Exam of Benumof

Although trauma and other emergency conditions do not always allow the time, an airway physical examination should be conducted prior to the initiation of anesthetic care and airway management in all patients whenever feasible. The intent of the airway examination is to detect anatomical or pathological physical characteristics that might indicate that airway management will be difficult. Currently, the ASA DA Guidelines have endorsed an easily performed 11-step airway physical examination, as originally proposed by Benumof (Table 4) (12). The decision to examine all or some of the components listed in Table 4 depends upon the clinical context and judgment of the practitioner. The order of presentation in the table follows the "line of sight" that occurs during conventional oral laryngoscopy and intubation. Of note, several of the examination components listed in Table 4 require an awake, cooperative patient (which is not always the case with trauma). For example, the Mallampati classification (Fig. 5), relating the size of the tongue to the pharyngeal space, requires the patient to open the mouth maximally and protrude the tongue as far as possible (13). In addition, the Mallampati classification is classically described in a patient sitting upright; whereas, trauma patients generally present to the TRS supine lying on a spine board. Furthermore, blunt trauma patients should not be asked to move their neck until the C-spine is cleared (Volume 1, Chapter 15) and should not be asked to sit up until the entire (C-T-L) spine is cleared. Because certain elements of this 11-step exam cannot be practically evaluated in the trauma patient, an abbreviated trauma airway examination is recommended.

Abbreviated Trauma Airway Exam

In the noncooperative and unstable patient, most elements of even an abbreviated exam are impractical. In addition, RDL would be likely performed regardless of examination results; either an RSI or a modification (as described subsequently) would be used. If intubation difficulty were encountered, the emergency airway adjuncts recommended in the ASA DA should be used (discussed later in detail). However, in awake, cooperative trauma patients requiring semi-urgent or emergent intubation, steps 1 to 10 can and should be evaluated (Table 4). Step 11, examination of the head extension and neck flexion should not initially be evaluated when C-spine injury is known or suspected. Even in the noncooperative, semi-urgent situation, the airway expert can check the length of the upper incisors, the mandibular space compliance, thyromental distance, neck length, and neck thickness to assess the relative difficulty of intubation, as the aforementioned components do not require patient cooperation.

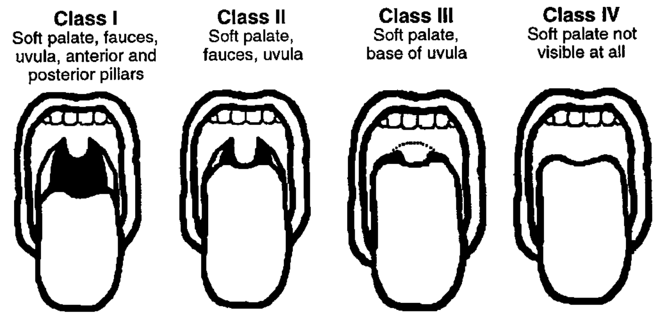

Figure 5 Mallampati classification. Classification of the upper airway relating the size of the tongue to the pharyngeal space based upon the anatomic features seen with the mouth open and the tongue extended. *Source*: Modified from Ref. 13.

CONVENTIONAL TRAUMA AIRWAY MANAGEMENT

Patient Preparation and Positioning

Regardless of whether an awake topicalized technique or an RSI technique is chosen, optimum patient positioning and preparation will improve intubation success. If an awake fiberoptic intubation is planned in a patient capable of flexing the lower back [i.e., absence of unstable thoraco-lumbar (T-L) spine injury], the head of the

Table 4 Eleven Step Airway Examination of Benumof[a]

Step	Airway examination component	Nonreassuring findings	Can evaluate in trauma patient
1	Length of upper incisors	Relatively long	Yes[b]
2	Maxillary–mandibular incisor relationship	Prominent "overbite"	Yes
3	Ability to prognath jaw	Unable	Yes
4	Interincisor distance	<3 cm	Yes
5	Visibility of uvula	Mallampati class III/IV	Yes
6	Shape of palate	Highly arched or narrow	Yes
7	Mandibular space compliance	Stiff, indurated, noncompliant	Yes[b]
8	Thyromental distance	<3 "normal finger" breadths	Yes[b]
9	Length of neck	Short	Yes[b]
10	Thickness of neck	Thick	Yes[b]
11	ROM of head and neck	Incomplete ROM. Assume incomplete ROM in C-spine injured patients	No (unless cleared) cannot examine ROM in unstable C-spine patients!

[a]Steps 1 to 10 can be evaluated in stable, cooperative trauma patients (even with known or suspected C-spine injury).
[b]Can be done, even in patient who is unstable, uncooperative (Steps 1, 7–10), and should be examined when possible.
Abbreviation: ROM, range of motion.

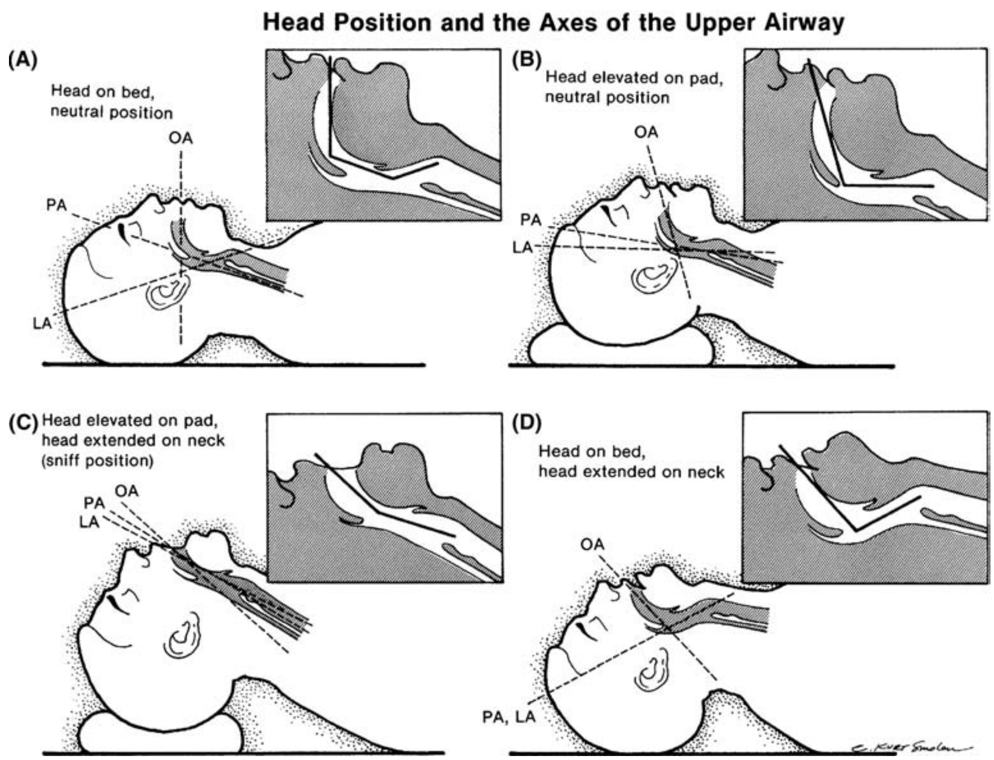

Figure 6 Head position and the axis of the upper airway. This diagram demonstrates the various head and neck positions in the supine patient and the corresponding oral axis (OA), pharyngeal axis (PA), and laryngeal axis (LA) in four different head positions. Each head position is accompanied by an inset that magnifies the upper airway and superimposes the continuity of these three axes within the upper airway. The upper left panel (**A**) shows the head in the neutral position with marked nonalignment of the various axes. In the upper right panel (**B**) the head is resting on a pillow, which causes forward flexion of the neck on the chest and serves to align the PA and the LA. However, the OA remains nonaligned. The lower right panel (**D**) shows extension of the head on the neck without concomitant elevation of the head on the pad resulting in nonalignment of the oral pharyngeal with the laryngeal and pharyngeal axes. The lower left panel (**C**) shows the head resting on a pad, which flexes the neck forward on the chest along with extension of the head on the neck, which brings all three axes into alignment (sniff position). This position allows for a direct view from the oral pharynx to the larynx, providing the tongue and soft tissues are elevated out of the way with a rigid direct laryngoscope. *Source*: From Ref. 68, p.123.

patient's bed should be elevated at least 45° to optimize intubating conditions (with C-spine injury, maintain cervical immobilization). However, in conditions where T-L spine injury is likely, the patient must remain supine with the entire spine maintained in line. The patient should also be psychologically prepared and the clinician must be patient in ensuring that the nasopharynx, oropharynx, and larynx are properly anesthetized with topical local anesthesia (e.g., lidocaine or cocaine) prior to commencing airway instrumentation.

For patients without concern for C-spine injury, who will undergo an RSI (standard or modified), the "sniffing position" (Fig. 6) is the optimum orientation for RDL-assisted orotracheal intubation. The sniffing position involves forward flexion of the neck on the chest and atlanto-occipital extension of the head at the neck. This aligns the oropharyngeal, laryngeal, and tracheal axes. The easiest way to accomplish this is to place at least two folded towels under the head of the supine patient.

The "sniffing position" is contraindicated whenever C-spine injury is suspected. In these patients, the head and neck are maintained in-line and immobilized throughout airway manipulation. The details of in-line immobilization (Fig. 7) and the standard RSI for trauma are provided subsequently.

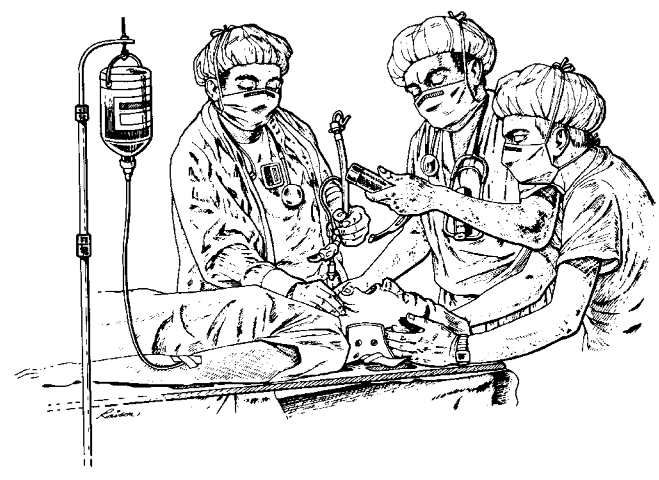

Figure 7 In-line cervical immobilization. The emergency intubation of the trauma patient with suspected C-spine fracture entails keeping the patient supine on a rigid spine board, applying cricoid pressure, and maintaining cervical in-line immobilization. In-line immobilization requires the assistant to immobilize the neck by holding a hand over each ear while keeping the shoulders and occiput firmly placed on the board, with a gaze directed straight up. *Source*: From Ref. 69.

Mask Ventilation

Types of Masks Used for Ventilation

Facemasks come in a variety of configurations but most airway experts prefer anatomically shaped masks as these best fit the patient's face as well as the clinician's hand. Adult masks come in small, medium, and large sizes (3, 4, 5). Most adults can be ventilated with a size 3 or 4 mask but occasionally a patient will have a large jaw requiring a size 5 mask. Children's masks come in newborn, infant, and children's sizes and should be provided in the pediatric code bag.

Mask Ventilation Techniques

The facemask must be applied firmly to the patient's face ensuring an adequate seal. Simultaneously, care is taken not to injure the bridge of the nose with excessive pressure. A single hand technique is acceptable if the airway is easy to ventilate (Fig. 8). However, if ventilation is difficult or impossible with only one hand, two hands should be used to hold the mask in place while a second person depresses the bag in an effort to ventilate the lungs (Fig. 9). Frequently, the application of a chin lift or "jaw thrust" (backward and upward pull of the jaw in supine patient) will open an airway and facilitate ventilation. The "jaw thrust" maneuver, rather than the chin lift, should be used in patients suspected of C-spine injury.

Oropharyngeal and Nasopharyngeal Airways

When the tongue and other soft tissues are maintained in the normal forward position as in the awake patient, the posterior pharyngeal wall remains unobstructed and the airway is generally open (Fig. 10A). This is particularly the case when the patient is sitting upright. The most common cause of airway obstruction occurs when the tongue and epiglottis fall back in supine, unconscious patients (Fig. 10B). This can be alleviated by the "jaw thrust" maneuver. Regardless of whether "jaw thrust" is successful, an oral or nasal airway (if not contraindicated) can be employed as an adjunct to BVM ventilation to open up a closed airway. Nasopharyngeal airways are relatively contraindicated in cases of coagulopathy or suspected cribriform plate injury (basilar skull fracture and massive facial injury) due to the increased risk of bleeding and the chance of ETT passage into the cranial vault, respectively.

Figure 9 Two-hand mask ventilation technique. With the two-handed technique the thumbs are hooked over the collar of the mask while the lower fingers maintain jaw thrust and the upper fingers are pulling the mandible into the mask while extending the head (arrows indicate direction of force). *Source*: Modified from Ref. 70, p. 109.

Both oral and nasal airways restore airway patency by separating the tongue from the posterior pharyngeal wall (Fig. 10C and D). A rigid oral airway can elicit a gag response from an awake patient and this can be followed by emesis. Soft nasal airways provoke less gag response than rigid oral airways. Soft nasal airways are frequently inserted in patients suffering from ventilatory failure who are awake and prone to gagging on the rigid oral airway.

Laryngeal Mask Airway

The LMA was originally used for elective anesthesia cases, and introduced as a rescue tool in the CNI–CNV situation. The most recent revision of the ASA DA algorithm (discussed further below) now places the LMA within the anesthetized limb of the pathway to be used whenever BVM ventilation is difficult. Ventilatory obstruction above the level of the cords (supraglottic) can be alleviated by the LMA because of its supraglottic placement (Fig. 11). However, the LMA is not an effective ventilatory device in cases of periglottic or subglottic pathology (e.g., laryngospasm, subglottic obstruction) (14).

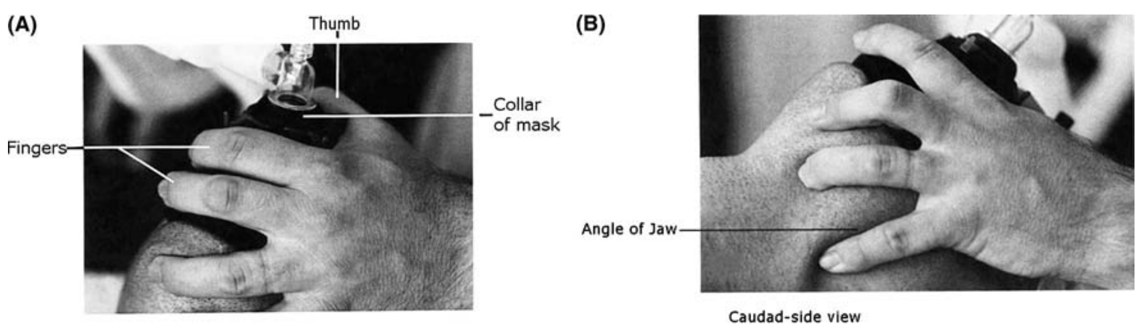

Figure 8 Mask ventilation one-hand technique. This figure shows the one-handed technique in holding a mask properly on a patient's face. The left figure (**A**) demonstrates the standard one-handed grip of the mask on the face. The thumb encircles the upper part of the patient's mask while the second and third fingers are applied to the lower portion of the mask with the fourth and fifth fingers pulling the soft tissue under the mandible up toward the mask. The right panel (**B**) demonstrates the one-handed mask grip while maintaining jaw thrust. The hand positions are altered such that only the thumb and the second finger encircle the mask while the third, fourth, and fifth fingers maintain upward and backward pull of the mandible "jaw thrust." Typically an oral airway would have been placed in the patient's oropharynx prior to manipulating the mandible with the "jaw thrust" maneuver. *Source*: Modified from Ref. 70, p. 107.

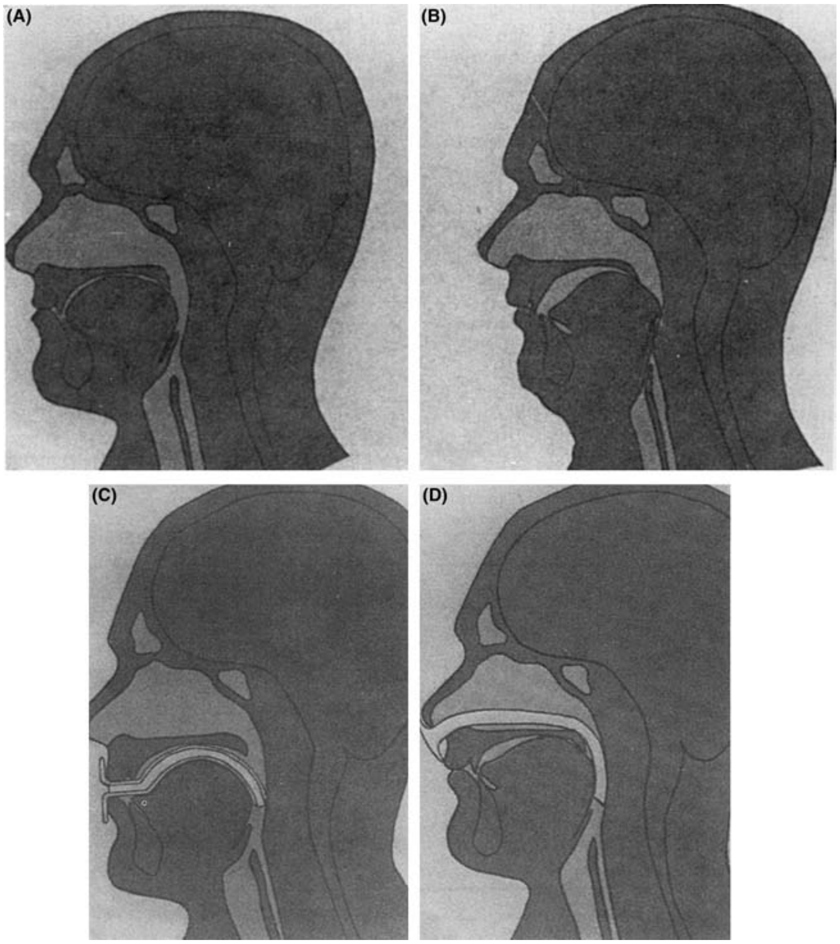

Figure 10 Normal airway, soft tissue obstruction, and use of laryngeal and nasopharyngeal airways. This series of four panels describes in sequence the normal (unobstructed) airway (**A**), the obstructed airway (**B**), and use of the oral (**C**), and nasal (**D**) airways. The normal airway (**A**) maintains the tongue and other soft tissues in the forward position allowing unobstructed passage of air. The next panel (**B**) demonstrates the typical obstructed airway of an unconscious supine patient. The tongue and epiglottis fall back to the posterior pharyngeal wall and occlude the airway. In panel (**C**) the use of the oral pharyngeal airway is demonstrated. The oral pharyngeal airway follows the curvature of the tongue and pulls it and the epiglottis away from the posterior pharyngeal wall providing a channel for air passage. In the last panel (**D**), the use of the nasal pharyngeal airway is demonstrated. This airway passes through the nose and ends at a point just above the epiglottis clearing the air passage. *Source*: Modified from Ref. 71.

The LMA is inserted blindly into the oropharynx forming a low-pressure seal around the laryngeal inlet thereby permitting gentle PPV with a leak pressure in the range of 15 to 20 cm H_2O. Therefore, LMA is relatively contraindicated in the presence of a known supraglottic hematoma or other expanding lesion (e.g., abscess) that might rupture. However, it can be very useful in other supraglottic obstructive conditions such as those due to swelling, edema, or redundant tissues. Placement of an LMA requires a completely anesthetized airway or an anesthetized patient (15). The LMA has been shown to rapidly restore efficient ventilation in numerous CNI–CNV situations (15–17).

More recently, the LMA has been utilized as an airway intubation "conduit" for various difficult intubation scenarios (particularly for FOB-assisted intubation) (14). Although the LMA usually seats around the larynx, it occupies a perfect central position only 45% to 60% of the time. **The authors caution against attempting to blindly pass an ETT through a functioning LMA due to the high blind passage failure rate (18–20), and the risk of doing harm to a tenuous airway.** This is particularly important in the setting of stridor, known or anticipated partial airway obstruction, and other conditions where blind passage risks converting a partial airway obstruction into a complete one (e.g., partial airway tear). These admonitions against blind manipulation in the setting of airway trauma also applies to the Fastrach™ LMA, despite the fact that this device is marketed for, and has been found to be useful in other emergency conditions where the risk of airway injury is low (21). Fiberoptic intubation is superior to blind manipulation, as it can be performed under direct vision with almost 100% success through several types of LMA, that are commercially available include the Classic™, Fastrach™, ILA™, among others (14).

Rigid Direct Laryngoscopy

Prior to performing laryngoscopy, the blade and handle should be tested to ensure proper functioning. The RDL is held in the left hand, so that the right hand is free to place the styletted ETT through the cords and into the trachea. The mouth is opened by simultaneously extending the head on the neck

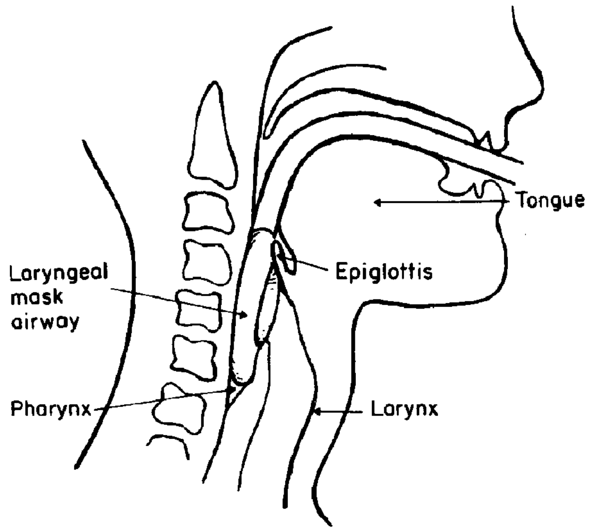

Figure 11 The normal anatomic position of the laryngeal mask airway (LMA). The proximal portion of the laryngeal mask rests upon the epiglottis, while the distal end extends into the pharynx at the upper end of the esophagus. The opening on the laryngeal mask overlies the laryngeal inlet. This figure demonstrates a prototypical LMA and is not meant to represent any particular commercially available device. *Source*: Modified from Ref. 72.

with the right hand (except in suspected C-spine injury where in-line immobilization is maintained) and using the small finger of the left hand (while holding the laryngoscope) to push the anterior part of the mandible in a caudal direction and opening the mouth (Fig. 12). As the blade enters the oral cavity, gentle pressure is applied on the tongue sweeping it left-

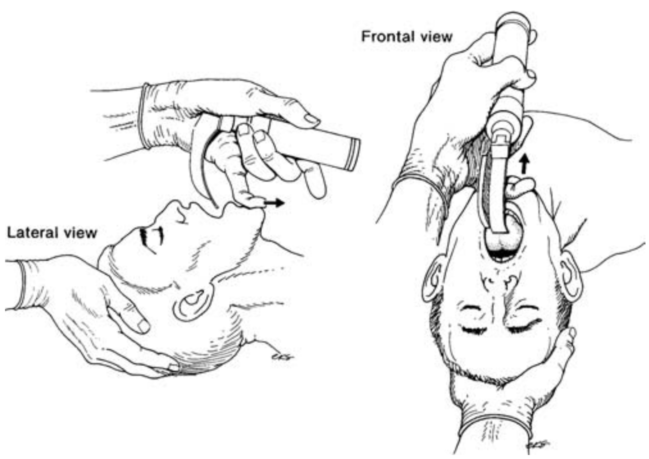

Figure 12 Opening the mouth for laryngoscopy: use of the little finger. The mouth can be opened wide by concomitantly extending the head on the neck with the right hand, while the small finger and the medial border of the left hand push the anterior aspect of the mandible in a caudal direction. The laryngoscope is held in the left hand while opening the mouth with this technique. As the blade approaches the mouth, it should be directed to the right side of the tongue. Gloves should be worn during laryngoscopy and the hands should be kept out of the oral cavity in order to limit contact with the patient's secretions. *Source*: From Ref. 68, p. 124.

ward and anterior (Fig. 13), thereby exposing the glottic aperture.

Two basic blade types are commonly used for laryngoscopy; a curved blade (Macintosh) and straight blade (Miller and Wisconsin). The curved Macintosh blade (Fig. 14) tip is placed in the vallecula after sliding the tongue leftward and anterior, while the laryngoscope handle is lifted in a forward and upward direction (stretching the hyoepiglottic ligament). This causes the epiglottis to move upward out of view, unveiling a view of the arytenoid cartilages and eventually the vocal cords. In contrast, the straight Miller blade (Fig. 15) is inserted under the epiglottis and then the epiglottis is elevated to expose the glottic aperture.

Six common errors can occur during laryngoscopy using a standard (Macintosh or Miller/Wisconsin type) RDL. First, the blade can be inserted too far into the pharynx elevating the entire larynx, which exposes the esophagus instead of the glottis. Secondly, for optimal laryngoscopy, the tongue must be completely swept to the left side of the mouth with the flange on the RDL blade. This is slightly more difficult to accomplish with the Miller blade because the flange is less prominent. Thirdly, novice laryngoscopists frequently rock the RDL in the patient's mouth using the upper incisor as a fulcrum in a self-defeating attempt to visualize the glottis. This can chip the patient's upper incisors and moves the glottic aperture further anterior out of view. The correct approach is to lift the handle anterior and forward at an approximately 45° angle (Fig. 14). Fourthly, proper sniffing position is not always achieved or indicated. Fifth, in obese barrel-chested patients and large-breasted women, it can be difficult to insert the blade in the mouth. Use of a short-handled RDL or removal of the blade from the scope handle and re-attaching once the blade is positioned in the mouth helps with this predicament. Finally, improper blade selection may hinder laryngoscopy and intubation. If the patient has a long floppy epiglottis, a Miller blade may be best; a large wide tongue may be best managed using a Macintosh blade.

In-Line Cervical Immobilization

Due to the significant incidence of C-spine injury in severe trauma, all blunt trauma patients should be suspected of having an unstable C-spine injury until proven otherwise. Rigid cervical collars, sand bags, rigid backboards, and other devices used to immobilize the C-spine can complicate airway management, especially when there is an abrupt and unexpected need for a definitive airway.

In-line immobilization of the C-spine is easy and effective if applied appropriately (Fig. 7). After induction and prior to laryngoscopy, the rigid cervical collar is removed to facilitate intubation. The patient's neck should be prevented from flexing, extending, or rotating during intubation; this is accomplished by in-line immobilization. Occasionally, immobilization of the neck may be overridden by the requirement of providing an adequate airway in hypoxemic patients (i.e., in the CNI–CNV patient not responding to emergency airway techniques), especially when unable to obtain a surgical airway. However, even under these extreme circumstances, the cervical movement should be limited to the minimum required to achieve airway patency.

Rapid Sequence Intubation (RSI) Principles

Trauma patients and others who require emergency intubation are at increased risk of regurgitation and aspiration,

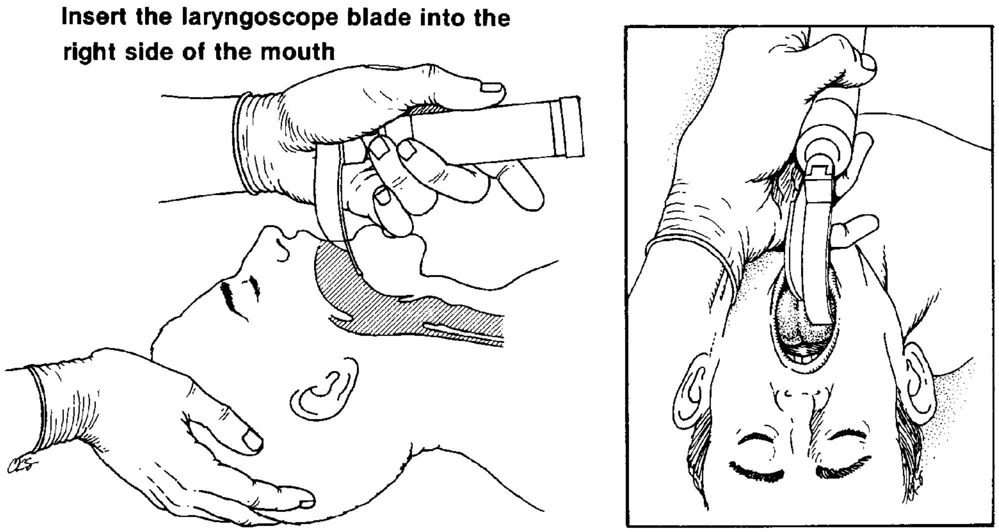

Figure 13 Inserting the laryngoscope blade into the right side of the mouth. This figure demonstrates the proper head and neck positioning for insertion of a curved (Macintosh) laryngoscope blade. The inset shows the blade entering the right side of the oral cavity so that the tongue will be moved towards the left side of the mouth with the large flange on the Macintosh blade, thereby creating a view of the larynx. *Source*: From Ref. 68, p. 125.

partly because they have not fasted prior to induction. **RSI techniques were developed to minimize the likelihood of regurgitation and aspiration.** Classically, RSI includes preoxygenation with 100% O_2 for five minutes (as discussed above), followed by the application of cricoid pressure, and in rapid sequence order an induction drug and a rapid acting neuromuscular blockade (NMB) drug (e.g., succinylcholine 1 to 2 mg/kg or Rocuronium, 1.2 mg/kg), administered without testing ventilation beforehand (Table 5). As soon as airway reflexes are lost, the RDL is used to visualize the glottis and facilitate placement of a styletted ETT. Cricoid pressure is maintained until $P_{ET}CO_2$ is detected from the putative ETT, equal bilateral breath sounds are auscultated and the intubating anesthesiologist declares that it may be released.

Cricoid pressure (Sellick maneuver) denotes downward (posterior) pressure on the neck overlying the cricoid cartilage. This cricoid pressure compresses the esophagus and is intended to decrease the likelihood of gastric contents leaking into the pharynx. Occasionally, cricoid pressure can impair the laryngoscopic view. "Laryngeal manipulation" is not analogous to cricoid pressure; it is the movement of the thyroid cartilage posterior to bring the laryngeal aperture into view. Use of a rigid

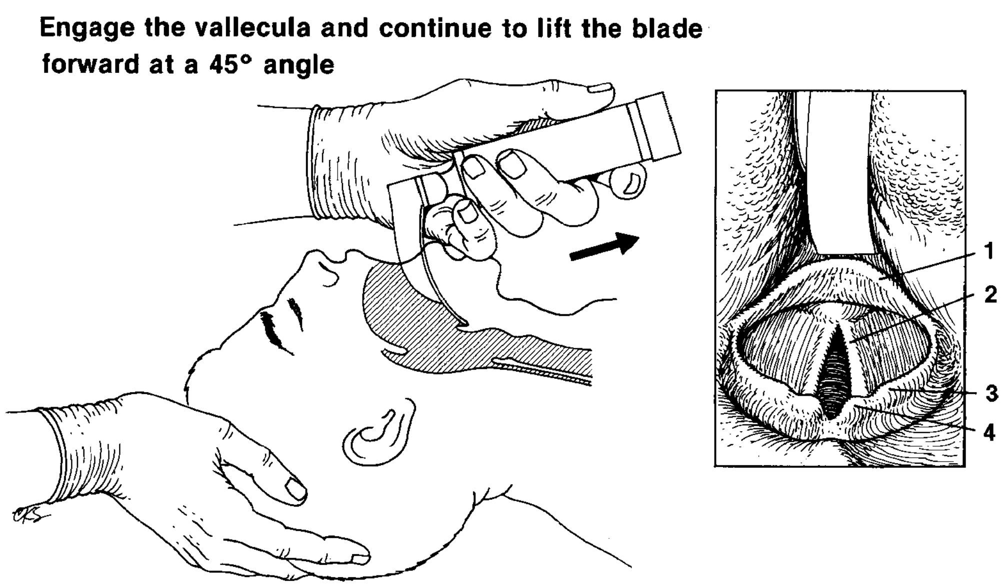

Figure 14 Correct position of the Macintosh laryngoscope blade in the vallecula. This figure demonstrates the correct position of the curved (Macintosh) laryngoscope blade in the vallecula and the angle of pressure that should be applied (45° from the patients axial line). The inset demonstrates the laryngeal view obtained when the Macintosh blade is used. 1 = epiglottis, 2 = vocal cords, 3 = cuneiform part of arytenoid cartilage, and 4 = corniculate part of arytenoid cartilage. *Source*: From Ref. 68, p. 127.

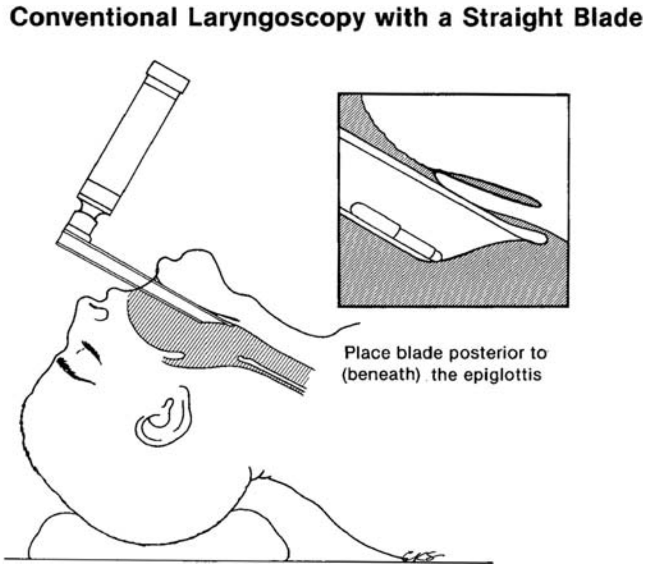

Figure 15 Laryngoscopic technique with a straight (Miller) blade. A straight (Miller) laryngoscope blade should pass underneath the laryngeal surface of the epiglottis, then the handle of the laryngoscope blade should be elevated at 45° angle similar to that used with a Macintosh blade. By lifting up the epiglottis the laryngeal aperture should come clearly into view. *Source*: From Ref. 68, p. 128.

stylet also increases the likelihood of intubation success in difficult-to-intubate patients (22,23). During intubation attempts, the patient should be carefully monitored by pulse-oximetry, heart rate, BP, and ECG. Intubation attempts should be interrupted by reoxygenation using BVM ventilation if the procedure takes more than 30 seconds or when desaturation (SpO_2 <90%) occurs. If intubation attempts fail and adequate oxygenation cannot be achieved with BVM ventilation, an LMA should be considered as per the ASA DA algorithm (14).

Modified Rapid Sequence Intubation Techniques

The RSI technique can be modified in at least two major ways: (*i*) institution of BVM ventilation prior to placement of the ETT and (*ii*) allowing SV to be maintained during placement of the ETT.

The application of BVM ventilation during RSI is indicated in instances where apnea is likely to result in rapid desaturation despite properly performed preoxygenation. Trauma and critically ill patients often suffer from conditions causing increased right-to-left transpulmonary shunting (e.g., pulmonary contusion, pneumonia, etc.) and thus require additional O_2 and ventilation after induction and prior to full effect of NMB drugs. This modification to the RSI technique involves gentle BVM ventilation with 100% O_2 while maintaining cricoid pressure (to prevent gastric insufflation and decrease the risk of regurgitation and/or aspiration).

The RSI technique can also be modified by maintaining SV. This modification is employed in situations where apnea may lead to inability to ventilate (e.g., patients with partial airway obstruction manifested by audible stridor) and when PPV might extend a partial airway disruption into a complete separation (e.g., tracheal or main stem bronchus tears). The maintenance of SV is also indicated in a patient who cannot tolerate the hemodynamic consequence of PPV (e.g., severe cardiac tamponade). An uncooperative patient with an obvious DA represents another patient condition where the maintenance of SV may be indicated. In this setting, a small dose of sedation should be administered to gain control of the situation and SV is preserved while employing cricoid pressure.

In situations where SV is maintained and the patient is sedated as needed, the trachea is often intubated using an FOB through an intubating mask (described in detail subsequently) (24). The proper amount of drug required to sedate the patient enough to manipulate the airway, but not so much as to result in apnea, varies, based upon the size of the patient, the amount of blood loss, and the levels of other drugs already administered.

THE DIFFICULT TRAUMA AIRWAY

Awake Techniques (Cooperative/Stable Patients)

An "awake" intubation technique is recommended for trauma patients with known or anticipated DAs provided they are cooperative, stable, and spontaneously ventilating. To optimize the conditions for successful intubation, cooperation is enhanced with proper mental and physical preparation. Although the ASA DA Guidelines do not endorse any particular awake intubation tool or methodology, an awake FOB-guided technique is generally the safest and most appropriate for stable trauma scenarios.

Table 5 Rapid Sequence Intubation Principles: Classic vs. Modified Techniques

Elements	$Pre\text{-}O_2$	Cricoid pressure	Induction drug followed by NMBD	BVM ventilation deferred until ETT confirmed	Confirm ETT with $PaCO_2$
Classical	+	+	+	+	+
Modified by allowing BVM ventilation (with cricoid pressure) prior to ETT	+	+	+	(−) Can BVM vent as needed to avoid hypoxemia	+
Modified by maintaining SV until ETT placement confirmed[a]	+	+	(−) Small sedative or induction drug doses given, so that SV is maintained[a]	(−) Can assist some ventilation, but goal is to maintain SV until ETT placed	+

[a]No NMB drugs given until ETT in place, or laryngoscopist convinced ETT placement will be easy.

Abbreviations: +, element is utilized during the technique of classical or modified rapid sequence technique; (−), not utilized; BVM, bag-valve-mask; ETT, endotracheal tube; NMBD, neuromuscular blockade drug; SV, spontaneous ventilation.

Even when a tracheostomy is planned, performing an awake FOB-assisted intubation under direct vision is recommended whenever able to achieve airway protection prior to performing the formal tracheostomy.

Adjunts for Unstable, Uncooperative, or Apneic Patients with Difficult Airways

There are three scenarios in which the need arises to intubate the trachea of an unstable, uncooperative, or apneic patient with pre-existing DAs. These situations include: (*i*) when the airway is not recognized to be difficult; (*ii*) the DA patient is already unconscious prior to presentation to the TRS; and (*iii*) the DA patient is hemodynamically unstable or unable to cooperate with an awake technique. In all of these conditions, the generally anesthetized limb of the ASA DA algorithm is followed. If intubation cannot be achieved, BVM ventilation should be attempted with enriched O_2 while applying cricoid pressure. In the CNI–CNV patient, the emergency limb of the ASA DA algorithm is followed. Various intubation modalities can be employed to maintain oxygenation prior to definitive ETT placement, the LMA being first. If ventilation is not successful with the LMA, other secondary emergency airway tools are tried including the ETC, TTJV (if not contraindicated), and the rigid ventilating bronchoscope. Various surgical airway techniques (cricothyroidotomy, tracheostomy) can also be considered.

Esophageal-Tracheal-Combitube

The ETC (Combitube) was developed by Michael Frass specifically for emergency airway management (25). The combitube comprises two longitudinally fused tubes made of polyvinylchloride (PVC), each fastened to a standard 15 mm airway connector at the proximal end (Fig. 16). The slightly longer of the two tubes is blue and is the primary (#1) conduit for ventilation in most situations. This longer tube has a blocked distal end with side hole openings at the pharyngeal level. There are two inflatable balloons on the Combitube: a proximal 100 cc latex pharyngeal balloon and a 15 cc PVC esophageal balloon near the distal portion. The combitube has a distal curve to match the adult human hypopharynx.

Greater than 96% of the time, when the Combitube is inserted blindly, esophageal placement results (Fig. 17) (26). The ETC is inserted until the upper incisors lie between the two proximal black rings etched onto the external surface of the tube. At that point, the proximal cuff is inflated with 100 cc of air via the blue pilot balloon. Next, the distal (esophageal) cuff is inflated with 15 cc of air via a white pilot balloon. Ventilation is then initiated via the #1 tube (blue) and $P_{ET}CO_2$ should be detected. If the $P_{ET}CO_2$ is detected, this confirms that the Combitube is properly placed esophageally and that ventilation has traveled through the side hole openings between the 100 cc pharyngeal balloon and the 15 cc esophageal balloon, then passing through the laryngeal aperture and into the trachea. In rare cases (<4%) where the ETC enters the trachea (Fig. 18), applying positive pressure to tube #1 will not ventilate the lungs and CO_2 will not be detected from the exhalate of tube #1 (25). At this point, tube #2 should be ventilated and assessed for CO_2. The ETC is a commonly employed rescue method for gaining emergency airway access, especially in the CNI–CNV situation (24).

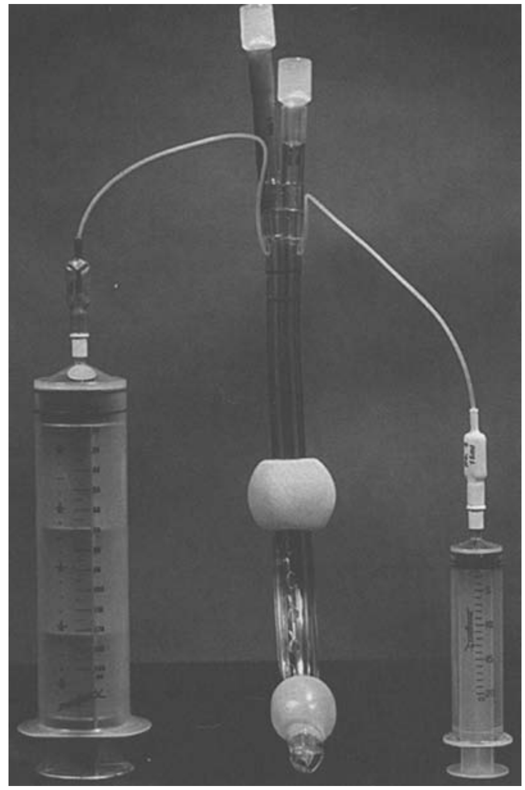

Figure 16 Frontal view of the ETC. This figure demonstrates the two longitudinally fused tubes comprising the Combitube; both cuffs are inflated with their corresponding syringes. Lumen #1 is the longer tube located on the left and lumen #2 is on the right. *Source*: Modified from Ref. 25.

Laryngeal Mask Airway

The LMA is not only an emergency aid used to establish ventilation in the CNI–CNV situation; it can also serve as a conduit for intubation once ventilation has been established. The ASA DA algorithm and guidelines do not

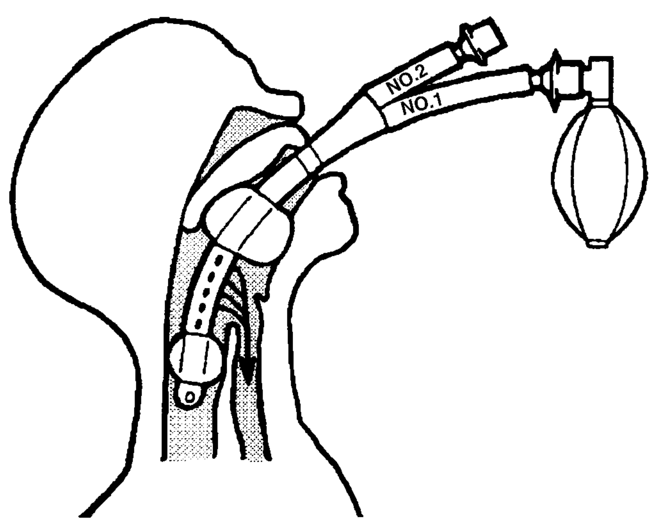

Figure 17 ETC in the usual (esophageal) position. This figure demonstrates the ventilatory pattern usually encountered when the Combitube is blindly placed in the esophagus. *Source*: Modified from Ref. 25.

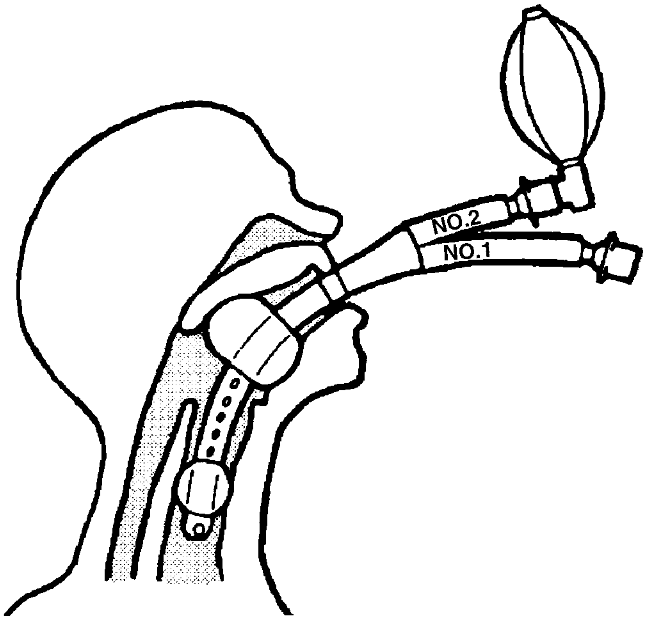

Figure 18 ETC in the tracheal position. This figure demonstrates the ventilatory pattern achieved when the Combitube is placed in the trachea. Tracheal positioning of the Combitube is rare as greater than 97% of the time the Combitube will enter the esophagus when placed blindly. *Source*: Modified from Ref. 25.

endorse any particular brand or subtype of LMA (Classic^{TM}, Fastrach, ILA^{TM}). However, whenever gastric volumes are expected to be large (e.g., following large meal, known bowel obstruction), the ProSeal may be superior, and whenever the LMA will likely be used as a conduit for FOB-assisted intubation, the Cookgas® ILA (Fig. 19) may be better because the ventilation tubing is wider and shorter than the other conventional LMAs, and does not have the epiglottis elevating bar that is present with the Fastrach.

Only in trauma situations where there is absolutely no concern of airway swelling (i.e., partial airway obstruction), direct airway injury (partial tear that could be made complete), stridor, or abscess should the Fastrach be used with blind ETT insertion. In all of the aforementioned conditions, blind manipulation is contraindicated. The Fastrach LMA is inserted blindly into the pharynx, forming a low-seal around the laryngeal inlet just like the Classic LMA (Fig. 11).

The special design features of the Fastrach (Fig. 20) include a rigid, anatomically curved conduit that is wide enough to accept an 8.0 ETT with an epiglottic elevating bar to facilitate the blind passage of the special ETT. Once ventilation is confirmed with the Fastrach LMA, the ETT can be blindly passed via the LMA conduit into the trachea. The blind intratracheal placement must be confirmed with $P_{ET}CO_2$, an EDD, or by FOB. The LMA can be kept in place until airway stability is achieved. Once successful ETT placement through the LMA is verified, the LMA can be deflated and removed using a push device to help keep the ETT in place. If intubation is not successful, ventilation can occur via the LMA between attempts.

Passage of an FOB through an LMA has a much higher chance of success (nearly 100% successful in most series) (14), compared with blind intubation via the Fastrach. A 6.0 mm ID-cuffed ETT (a nasal RAE tube is most suitable due to its

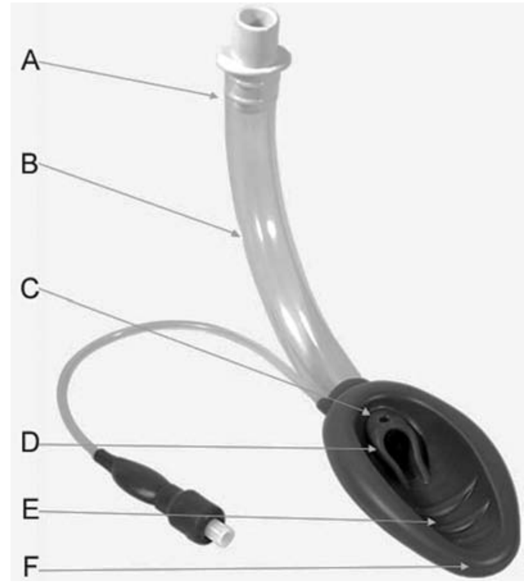

Figure 19 Cookgas® Intubating Laryngeal Airway (ILA^{TM}). The Cookgas® ILA^{TM} has several benefits over other LMAs for emergency airway use: (**A**) 15 mm airway connector ridges facilitate easy removal for fiberoptic airway management, and improved tube seal upon replacement. (**B**) Oval-shaped hyper-curved airway ventilation tube resists kinking. In addition, the relatively large internal diameter accommodates large-sized adult ETTs: 2.5 ILA^{TM} allows 6.5 ETT, 3.5 ILA^{TM} allows 7.5 ETT, 4.5 ILA^{TM} allows 8.5 ETT. Furthermore, the relatively short length of ventilation tube facilitates fiberoptic intubation. (**C**) The auxiliary airway hole improves airflow and prevents suction effects from drawing up epiglottis inside the airway tube. (**D**) The keyhole shaped airway outlet directs both FOB and ETTs toward the laryngeal inlet, and is anatomically engineered to align with the glottic chink. (**E**) The mask ridges move against posterior larynx improving anterior seal. (**F**) Recessed front improves posterior pharyngeal fit and ILA stability. *Source*: Courtesy of Mercury Medical, Clearwater, Florida, U.S.A.

additional length) may be passed over the FOB and through the shaft of the numbers three- and four-sized Classic LMA, whereas a 7.0 mm ID-cuffed ETT will only fit through the shaft of the number five-sized Classic LMA. Subsequently, if a larger ETT is required, the 6.0 or 7.0 mm ID-cuffed ETT can be exchanged for a larger ETT using an airway exchange catheter (AEC) (as described in Volume 2, Chapter 29) (15). The various sized ETTs that fit through all sized LMAs and the FOBs that fit through these ETTs are displayed in Table 6. Alternatively, and preferably when the glottic chink is expected to be of normal size, the authors recommend using the newer blue intubating LMA (ILA-by Cookgas®, Mercury Medical, Clearwater, Florida, U.S.A.). A large size of 4.5 will allow passage of an 8.0 or 8.5 ETT (Fig. 19).

Figure 21 shows the use of the bronchoscopy elbow adapter, 6.0 mm ID-ETT and LMA for the continuous ventilation FOB intubation technique for both a nasal RAE and standard 6.0 mm ID ETTs. With a 4.0 mm OD FOB/6.0 mm ID-ETT combination, the space available for ventilation around the FOB corresponds to a 4.5 mm ID-ETT.

The LMA, as a ventilatory device and/or intubating conduit, can be placed into the ASA DA algorithm in three different places. These are: (*i*) on the "awake intubation"

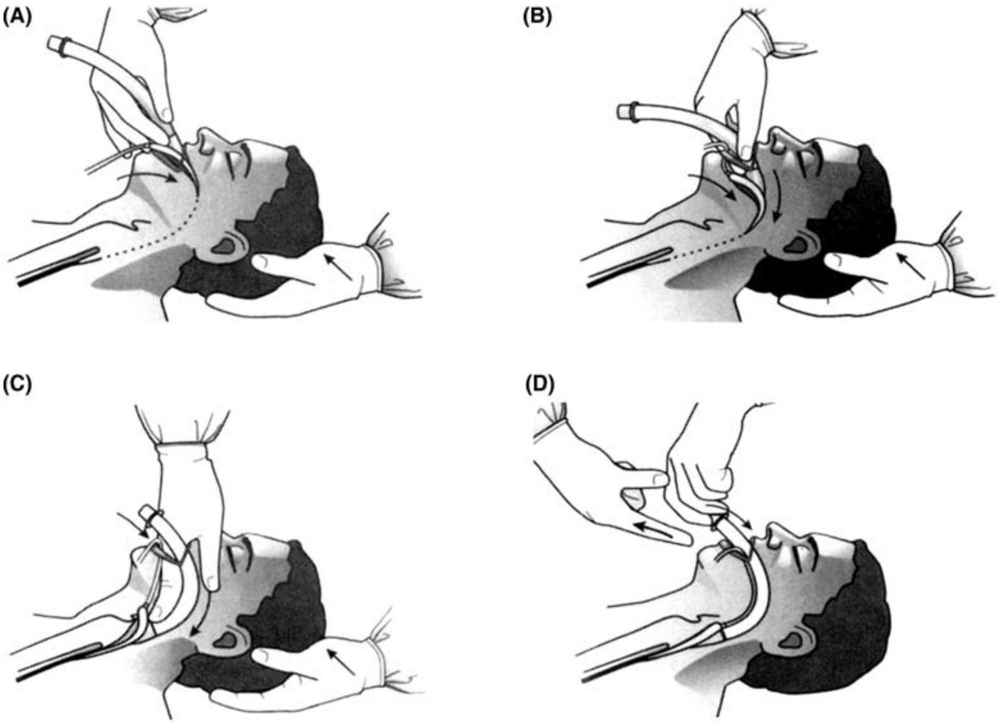

Figure 20 Insertion of the laryngeal mask airway (LMA). (**A**) The tip of the cuff is pressing upward against the hard palate by the index finger while the middle finger opens the mouth. (**B**) The LMA is pressed backward in a smooth movement. Notice that the nondominant hand is used to extend the head. (**C**) The LMA is advanced until definite resistance is felt. (**D**) Before the index finger is removed, the nondominant hand presses down on the LMA to prevent dislodgment during removal of the index finger. The cuff is subsequently inflated, and outward movement of the tube is often observed during this inflation. *Source*: Courtesy of LMA North America, Inc., San Diego, California, U.S.A.

limb of the algorithm as a conduit for FOB-guided tracheal intubation, (*ii*) on the "anesthetized" limb as both a life-saving ventilatory device, and (*iii*) as a conduit for FOB-assisted tracheal intubation.

Generally, the largest FOB that will fit through the ETT is best to maximize the ability to pass the ETT through a normal-sized adult glottis. The possibility of the ETT hanging up at the glottis is more common with use of the pediatric-sized FOB. However, if the patient has a small glottic chink, then a smaller FOB and ETT is better. If a 4.0 or less millimeter OD FOB is used with either the 6.0 or 7.0 mm ID-ETT, the lungs can be continuously ventilated around the FOB while it is contained within the ETT by passing the FOB through the self-sealing diaphragm of a bronchoscopy elbow adaptor. The distal and proximal ends of the bronchoscopy elbow adaptor are connected to the ETT and ventilatory apparatus, respectively.

Rigid Bronchoscope

A rigid bronchoscope is a straight, metal, lighted tube capable of visualizing the large airways with ventilatory

Table 6 Relevant Diameters of the Different-Sized Laryngeal Mask Airway, Endotracheal Tube, and Fiberoptic Branchoscopy that Fit into the Endotracheal Tube

LMA MFGR	Size	Patient weight (kg)	LMA (ID mm)	Cuff volume (mL)	Largest ETT inside LMA (ID mm)	Largest FOB inside ETT (mm)
Classic™	1	<6.5	5.25	2–5	3.5	2.7
Classic™	2	6.5–20	7.0	7–10	4.5	3.5
Classic™	2.5	20–30	8.4	14	5.0	4.0
Classic™	3	30–70	10	15–20	6.0 cuffed	5.0
Classic™	4	>70	10	25–30	6.0 cuffed	5.0
Classic™	5	>90	11.5	25–30	7.0	6.5
Cookgas®	2.5	20–50	10	20–25	6.5	6.5
Cookgas®	3.5	50–70	12	25–30	7.5	6.5
Cookgas®	4.5	>70	14	25–30	8.5	6.5

Classic™ LMA (LMA, North America, Inc., San Diego, California, U.S.A.).
Cookgas® ILA™ (Mercury Medical, Clearwater, Florida, U.S.A.).
Abbreviations: ETT, endotracheal tube; FOB, fiberoptic bronchoscopy; ID, internal diameter; LMA, laryngeal mask airway; MFGR, manufacturer.

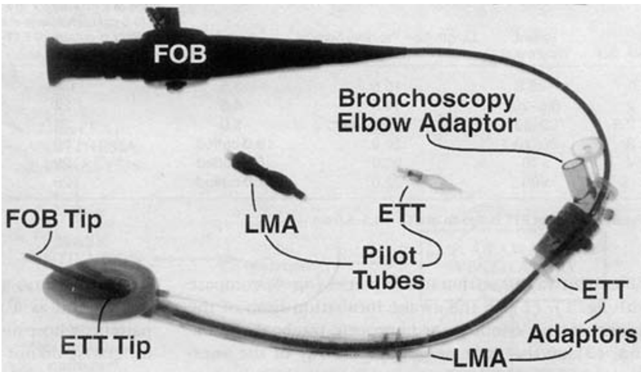

Figure 21 A patient can be continuously ventilated during fiberoptic intubation using the laryngeal mask airway (LMA) as a conduit for the fiberoptic bronchoscope (FOB). By passing a 4.0 mm OD fiberscope through the self-sealing diaphragm of a bronchoscopy elbow adaptor and the tip of a cuffed 6.0 mm internal diameter-endotracheal tube (ID-ETT) to the level of the grille on the LMA, ventilation can occur around the FOB but within the lumen of the ETT; the deflated cuff of the ETT inside the shaft of the LMA makes a tight enough seal to permit positive pressure ventilation. Once the FOB is passed well into the trachea, the 6.0 mm ID-ETT is pushed over the FOB into the trachea until the adaptor of the ETT is against the adaptor of the LMA. *Abbreviations*: ETT, endotracheal tube; FOB, fiberoptic bronchoscopy; LMA, laryngeal mask airway. *Source*: From Ref. 14.

capacity through the associated ventilating side port (Fig. 22). The rigid bronchoscope is effective in cases of large airway masses and bleeding. In the ASA DA algorithm, the application of the rigid bronchoscope is recommended as an emergency airway tool in the CNI–CNV situation, especially when the LMA has failed or is contraindicated.

The Bainton pharyngolaryngoscope blade (Figs. 23 and 24) is a straight, tubular blade with a shallow vertical portion at the proximal end and a 7 cm tube in the distal portion (with an intraluminal light source protected from secretions and obstruction). **The Bainton Blade is useful in many situations where a conventional rigid bronchoscope would be indicated.** One such indication is glottic visualization and emergency intubation of patients with pharyngeal space restrictions, such as that which occurs after major burns or other etiologies of supralaryngeal edema (and or hemorrhage). An ETT with an inner diameter of 8 mm or smaller will fit. The 15 mm airway adapter must be removed from the ETT during passage. A stylet is "optional" (but recommended by the authors). The styletted ETT passes easily through the tube of the blade without

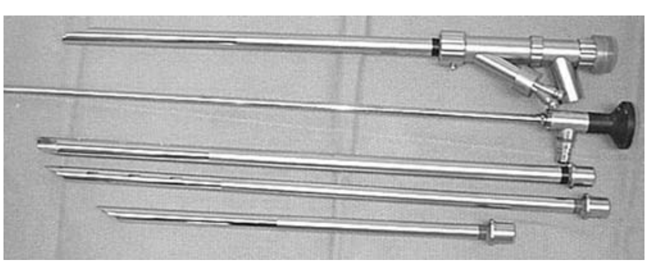

Figure 22 Rigid bronchoscope with ventilating side port, optic guide, and several sizes shown.

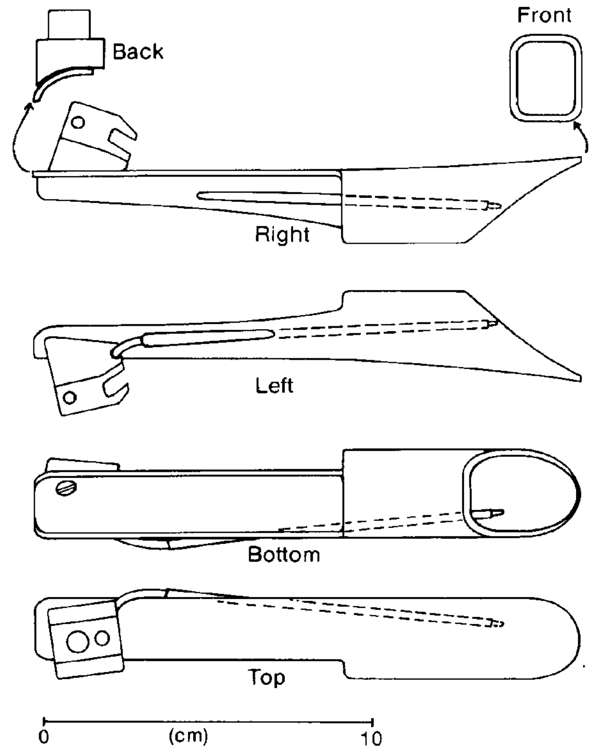

Figure 23 Bainton pharyngolaryngoscope. Scale drawing of the Bainton pharyngolaryngoscope. *Source*: From Ref. 73.

significantly obstructing the view. Once the ETT is in the trachea, the balloon is inflated, then the stylet and syringe are removed, and the Bainton Blade is removed over the ETT, followed by insertion of the 15 mm airway adapter and connection to a ventilation source and CO_2 detector.

Surgical Airway Options

Transtracheal Jet Ventilation

TTJV is another method of gaining emergency ventilation in a CNI–CNV patient. It is a temporizing (life-saving) technique that should be considered when the reason for failure to ventilate is supralaryngeal or peri-laryngeal (e.g., laryngeal fracture) and the LMA and Combitube have failed.

The TTJV technique involves palpating the cricothyroid membrane and advancing a 14 gauge angiocatheter through the membrane in the midline aimed 30° to 45°, and caudally from the perpendicular direction (Fig. 25). The intratracheal position of the catheter must be verified by attaching a syringe to the catheter and attempting to aspirate air (if air is not aspirated, the catheter may not be in the trachea and should be removed). When free flow of air is documented, the syringe is removed from the hub of the intravenous catheter and replaced by the Leur adaptor of a high pressure TTJV inflation system (Fig. 26). The TTJV inflation system must have 25 to 50 psi of pressure in order to allow flow down the small (14-gauge) bore catheter.

The natural airway must be maintained during exhalation and occasionally this requires some jaw thrust. TTJV can maintain oxygenation and adequate ventilation for over 40 minutes (27). Indeed, TTJV can take place while a definitive airway is established by FOB intubation or during the surgical creation of a tracheostomy.

TTJV is an extremely effective means of providing oxygen in the setting where the obstruction to ventilation

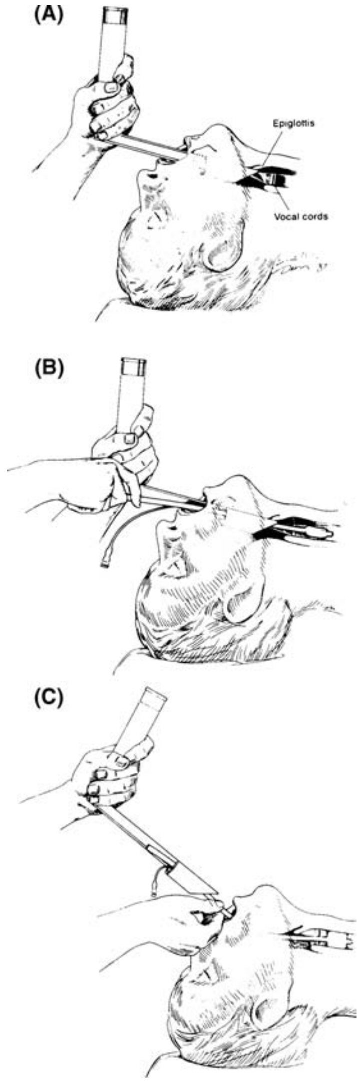

Figure 24 Schematic of intubation technique with Bainton pharyngolaryngoscope. (**A**) Tubular portion fits within the pharyngeal space. Tip of blade elevates epiglottis to permit laryngeal view. (**B**) Endotracheal tubes (ETT) without an adapter (stylet optional) is inserted into tubular portion of blade and advanced into larynx. ETT cuff is inflated. (**C**) SYRINGE and stylet are removed from ETT and pharyngolaryngoscope is withdrawn from mouth. Right hand of operator stabilizes ETT as blade is elevated over proximal end of ETT and cuffed pilot tube. *Source*: From Ref. 73.

is at or below the level of the glottis. **In airway injuries involving a tear between the glottis and the distal tracheobronchial tree, TTJV is absolutely contraindicated because the PPV can cause a pneumothorax, pneumomediastinum, or even convert a partial airway tear into a complete airway separation.**

Cricothyroidotomy—Percutaneous

The same technique described for TTJV is used to place a thin wall (14G or larger) needle into the trachea. Once the needle is confirmed to be intratracheal, a wire is passed through the needle into the trachea using the Seldinger technique (Fig. 25). Maintaining the guidewire several centimeters into the trachea, the cricothyrotomy site is dilated. Then, using the Seldinger technique, the cricothyrotomy

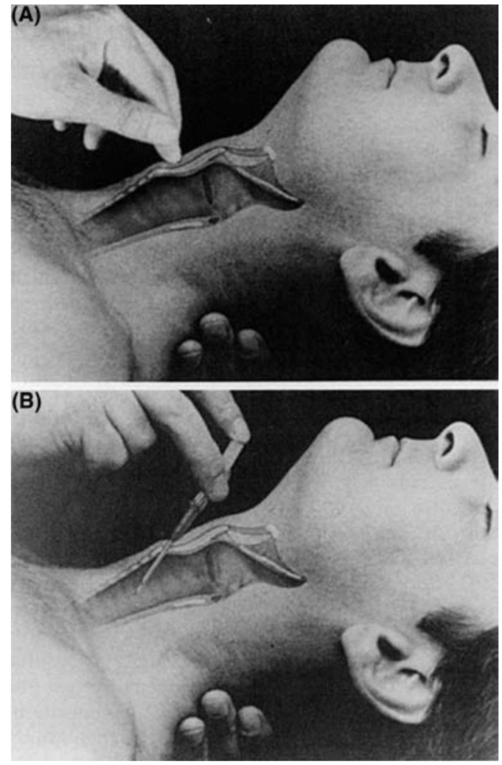

Figure 25 This figure demonstrates a 14-gauge angiocatheter passing through the cricothyroid membrane at an angle approximately 30° caudal from the skin. After achieving this position the metal stylet is withdrawn and a syringe is applied to the catheter to confirm intratracheal position; aspiration of air is the expected endpoint if the 14-gauge catheter is truly in the tracheal lumen. *Source*: From Ref. 74.

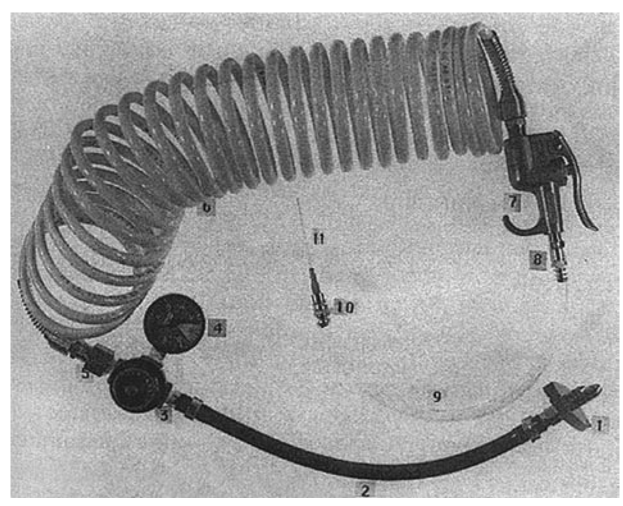

Figure 26 This figure demonstrates the equipment used for pressurizing the already placed transtracheal catheter. (1) Wall oxygen pressure quick disconnect device; (2) Green Chemtron O_2 hose; (3) NPT hose barb connector; (4) Bird regulator gauge (0–50 psi); (5) NPT air hose connector; (6) high-pressure self-coiling air hose; (7) jet injector valve; (8) NPT hose barb connecting the injector valve to clear soft flexible tubing (9); hose barb connecting to the clear tubing with a standard Becton/Dickinson male Luer lock connector (10); and transtracheal ventilation intravenous catheter with standard hub (11). *Source*: From Ref. 27.

tube is advanced, confirmed to be intratracheal, and secured in place.

Cricothyroidotomy—Open
Cricothyroidotomy is the emergency surgical airway of choice (vs. tracheostomy) primarily due to the ease of determining anatomic landmarks (Fig. 27). The thyroid cartilage is stabilized and an incision is made through the skin and subcutaneous tissue overlying the cricothyroid membrane. The membrane is then opened with a stab incision and an ETT or cricothyrotomy tube is inserted, and placement confirmed in the usual fashion. Of note, whenever a formal tracheostomy can be performed, it is favored over the emergency cricothyroidotomy to decrease the risk of subglottic stenosis frequently seen with cricothyrotomy.

Tracheostomy
Tracheostomy is less desirable in emergency airway scenarios than cricothryoidotomy because it is slower, requires additional steps, and has greater potential for bleeding. Optimally, a transverse skin incision is made in midline position (for cosmetic and healing purposes). However, in emergency situations with novice surgeons, a vertical incision can be made in the midline of the neck (to minimize bleeding and to avoid the anterior jugular veins) overlying the trachea (Fig. 28). Next, skin and subcutaneous tissue are divided with a scalpel through the platysma, the strap muscles, and potentially the thyroid isthmus. Once the first few tracheal rings are exposed, a horizontal incision is made between the first and second tracheal rings and the tube is introduced into the trachea. Percutaneous placement of a tracheostomy tube can be performed but is recommended under bronchoscopic guidance as to reduce the chance of paratracheal insertion and to document real time intratracheal position of the needle, wire, dilators, and the tracheostomy tube.

Blind Intubation Techniques (Not Recommended with Stridor)

Blind techniques are employed in the trauma patient only as a means of last resort, when other safer techniques have failed. **Blind intubation techniques are contraindicated in the setting of stridor, known mass expanding lesions, or known partial airway injuries where blind manipulation can change a partial airway obstruction into a complete obstruction.** Some techniques include the frequently used blind nasal approach (in awake spontaneously ventilating patients), as well as techniques that are typically relegated to anesthetized patients, including light wand, and retrograde wire. The nasal approach being the most commonly employed blind technique will be described in some detail. Preparation and topical anesthesia for a blind nasal intubation is the same as will be described for FOB.

Blind Nasal Intubation

In addition to the precautions listed above, a blind nasal intubation is contraindicated in the presence of maxillofacial trauma where fracture of the cribiform bone is possible and in the setting of nasal bleeding or coagulopathy. When performing a blind nasal intubation, the patient should be sitting upright at 45° (rarely appropriate in the acute trauma setting), spontaneously ventilating and if possible, awake and cooperative. The ETT is placed in the already dilated and anesthetized nasal passage and the airway expert's ear is placed near the 15 mm connector end of the ETT.

As the ETT is passed down the nasal passage and towards the glottic aperture, the airway sounds from the patient will become much louder than previously noted. At this point, the airway expert should ask the patient to pant or take some deep breaths (these maneuvers tend to open the glottic aperture) and the ETT should be advanced during inspiration. Using this maneuver, the ETT is more likely to enter the larynx because of the patient's inhalation efforts.

It is occasionally beneficial to use a special flexible tipped ETT known as an Endotrol tube during blind intubation attempts. The Endotrol tube allows the intubator to flex the ETT anteriorly while advancing the tube (Fig. 29). Clinical endpoints alerting the physician that the ETT has entered the patient's trachea include: (*i*) the patient is no longer able to speak, (*ii*) increased secretions are heard emanating from the ETT with exhalation, and (*iii*) coughing is elicited as the ETT passes down the larynx into the trachea. However, following placement of the ETT, its endotracheal position

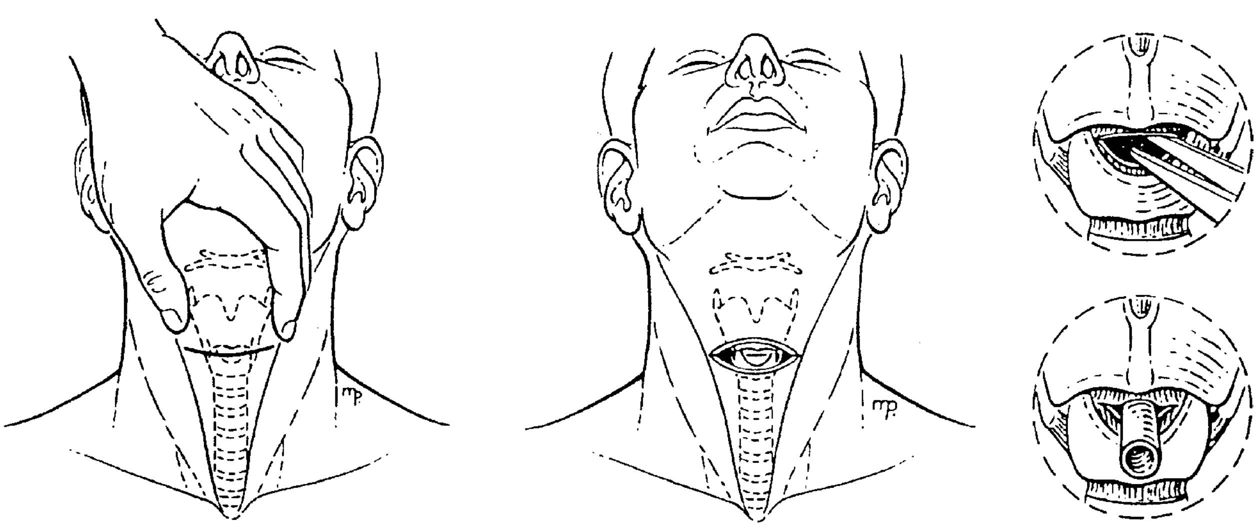

Figure 27 Surgical cricothyroidotomy. Horizontal skin incision, incision of cricothyroid membrane, dilation of the opening, and introduction of a ventilation tube. *Source*: From Ref. 75.