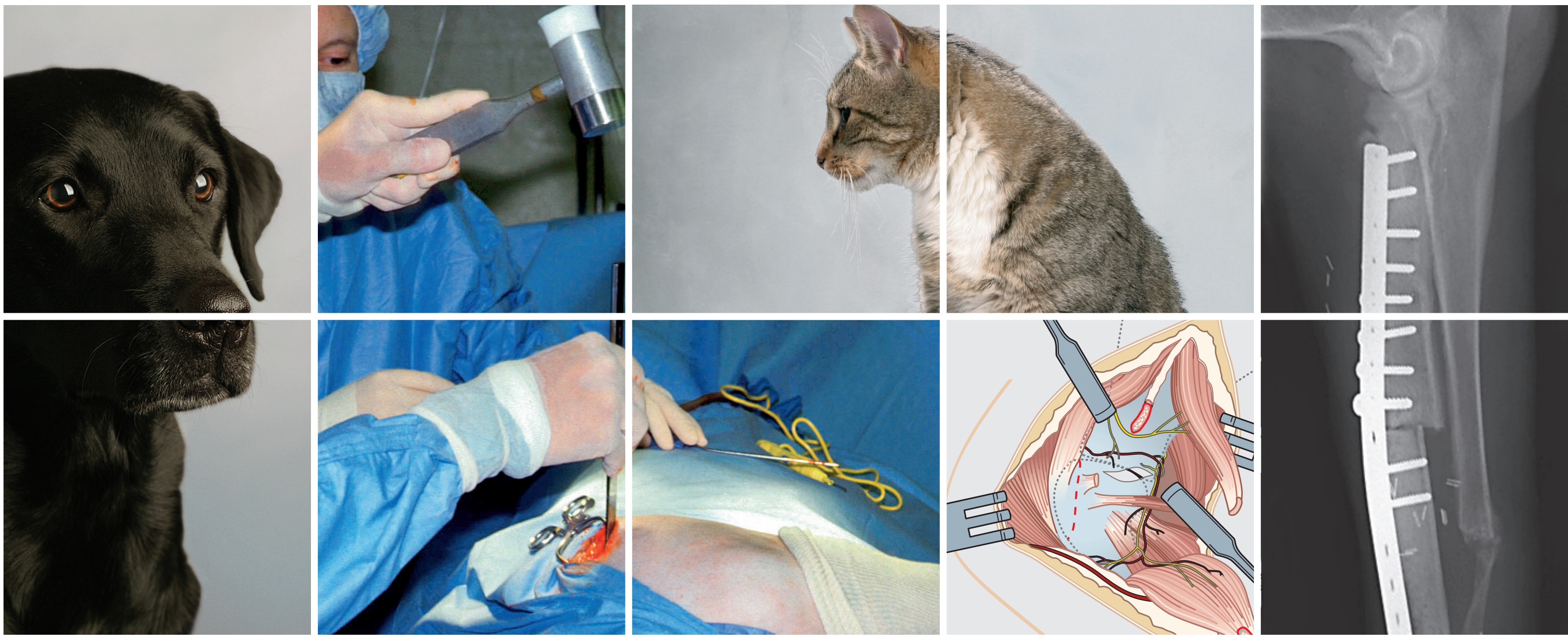
AO Publishing

Ann L Johnson, John EF Houlton, Rico Vannini

AO Principles of Fracture Management in the Dog and Cat



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Ann L Johnson John EF Houlton Rico Vannini

AO Principles of Fracture Management in the Dog and Cat

450 Illustrations

AO Teaching Videos and Animations on DVD-ROM

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Foreword

Geoffrey Sumner-Smith

"On peut amener le cheval a la fontaine, mais on ne peut le forcer boire." *(French proverb)*

This new text joins a family of previously published textbooks that have been dedicated to the principles adopted and vouchsafed by the AO (Arbeitsgemeinschaft für Osteosynthesefragen). The techniques employed by the editors and publishers in presenting the material are new to AO small animal orthopedics. The result is a splendid text for both teachers and pupils.

"A bringer of new things" *Tennyson's Ulysses*

In their wisdom, the editors selected 25 authors to undertake the task of writing new chapters that encompass current thinking with regard to the treatment of fractures in dogs and cats. That the majority of the authors have not previously published in an AO book is very refreshing and brings new contributors to the cadre. The cornucopia of their labor has resulted in delectable delights for the table of the operating small animal orthopedist. Because there are so many new dishes to be plunged, it is advisable to work slowly through the menu set before one—fully digesting each dish, before moving on to another. It is indeed a pleasure to read chapters concerned with preoperative preparation, perioperative pain control, anaesthesia, radiography, postoperative care, and rehabilitation. In an anxiety to learn new fracture techniques, sometimes some of these areas are not given sufficient attention.

Too often there is a tendency for the occasional operator to look for a diagram or radiograph in a text that matches a radiograph of a patient displaying the same skeletal trauma, attempting to find the step-by-step resolution of the fracture or other osteological disaster. And again, all too often the veterinary surgeon, having found what looks to be the correct recipe in the tome consulted, forgets that to every fractured bone there is a dog or cat attached! This state of affairs may lead to an operation that is ill conceived, and is usually to the detriment of the patient.

In this new book the editors have enlarged upon past systems recorded in previous books, and present you, the reader, with a very thoughtful and professional treatise. They have also been at pains to show the principles of "sufficient stabilization", including aftercare according to the particular type of fracture, as we currently understand them. Over the past decade, since the appearance of the last book on the principles of fixation, there have been significant changes in the genre of stabilization. Those who ignore the advice given in the perioperative chapters, do so at their own peril, and much more to the point, at the peril of their patients. So it is essential for anyone embarking upon orthopedics according to the principles of the AO, to "read, mark, learn, and inwardly digest" the perioperative chapters in this book before they pick up a scalpel.

Over the years since the first AO textbooks appeared, many changes have taken place in the methods by which new knowledge is disseminated. This new small animal textbook has benefited from the production of similar books for those who deal with orthopedics in human patients, and also our colleagues in the equine surgery field. In those texts, new and innovative publishing techniques were used, which have been followed in the production of this book.

Judicious use has been made of simple line diagrams, enhanced by coloring of just the major anatomical structures. The results are quite excellent. The supporting text has adopted two techniques of presentation, designed to emphasize important points, which are shown in bold type. In addition, color-backed vignettes in the margins drop in pearls of wisdom in an effort to save the surgeon from possible catastrophes. Before starting an operation, the wise surgeon, no matter the depth of experience, would do well to turn to the vignettes appropriate to the task to be undertaken. They sparkle with good common sense.

Three other techniques of "getting the message across" have been added to this new text. To whit, the use of intraoperative colored photographs, animations of particular techniques and video clips taken from the official AO Veterinary (AO Vet) laboratory tapes. The two latter items are designated at the appropriate place in the text and direct one to the DVD-ROM that accompanies this book. The use of moving images makes a valuable contribution to learning and may be studied at any time, again and again.

In their wisdom, the editors have not attempted to include all of the techniques for fracture care. They have shown techniques that, in the opinions of the authors, are currently considered to be good. To try to show more would only be confusing to the newcomer to the AO. No doubt as newer knowledge appears in print, particularly at the cellular level, modifications will be made to forthcoming dogma.

So in the words of the above ancient French proverb:

One may lead the horse to the fountain, but one may not make him drink.

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March 2005

Preface

The introduction of the AO philosophy to veterinarians occurred in the mid-1960s. This philosophy was directed to providing patient care that encouraged early weight bearing postoperatively, and a rapid return to function and mobility. The innovative methods of treating fractures allowed patients to have a shorter recovery period, minimized the need for external coaptation and provided optimal results for fracture management. Veterinarians subsequently adapted and modified the principles and implants for use in animals, conducted clinical and experimental research, documented treatment and results, and participated in educational courses through out the world. Thus the principles of AO became the gold standard for fracture management in animals and remain so as we enter the 21st century.

The concept of a comprehensive textbook describing the AO principles of fracture management for small animal veterinarians is not new. The first edition of the "Manual of Internal Fixation in Small Animals", edited by Drs W O Brinker, R B Hohn and W D Prieur, was published in 1983. The second edition, edited by Drs W O Brinker, M L Olmstead, G Sumner-Smith, and W D Prieur, was published in 1997. Both textbooks offered state of the art information on bone biology, metallurgy, mechanics, and AO principles of fracture treatment as applied to small animal orthopedic surgery. This textbook builds on the foundation established by these pioneers in veterinary fracture management, and we, the editors, would like to acknowledge the contributions of these outstanding orthopedic surgeons without whom this project would have been impossible.

The "AO Principles of Fracture Management in the Dog and Cat" emphasizes the selection and application of optimal methods of fracture stabilization. This textbook is designed to convey the necessary information to both the student of veterinary surgery and the practising veterinary surgeon. The content is based on the current concepts of AO teaching with emphasis on the biology of fracture healing. Multiple methods of description are used including text, highlights, illustrations, animations and video clips. The entire book is provided on DVD-ROM and is formatted for viewing on a computer screen. We believe the versatility of this book provides the optimal learning experience for the reader.

The textbook starts with an overview of AO philosophy and principles and closes with an appendix chapter regarding implants and materials. These texts are taken from the book "AO Principles of Fracture Management" in humans, courtesy of AO Publishing and we duly acknowledge the respective authors.

Following the introduction, the textbook proceeds to describe perioperative considerations for managing the fracture patient, commencing with preoperative evaluation and treatment; working through fracture planning and documentation; anesthesia and pain management protocols; fracture reduction techniques; and ending with concepts of rehabilitation. Implant systems for achieving osteosynthesis, including plates and screws, external and internal fixators, and intramedullary implants are discussed in detail followed by a comprehesive review of the biology of bone healing, including methods for encouraging rapid bone formation.

The majority of the textbook provides details for management of fractures of each bone, starting with the axial skeleton and progressing to the long bones and distal extremities. Each chapter includes pertinent surgical anatomy and surgical approaches, preoperative considerations, operative techniques, postoperative care and prognosis. Although fracture management with bone plates and screws is the primary focus of this textbook, other methods of stabilization are described where appropriate.

The final chapters of the textbook contain the topics of reconstructive bone surgery, including a comprehensive description of corrective osteotomies and fracture complications. While emphasis is placed on avoiding such complications, their management is described in detail. Finally, techniques for joint arthrodesis are included. The glossary at the end will help to guide you through the textbook.

We would like to express our sincere appreciation to all those who took part in producing this textbook, the first of its kind in small animal orthopedic surgery. Our thanks go to AO Publishing, particularly Martina Spaeti and Renate Huter, as Project Coordinators, and Sandra Taddei, as Graphic Designer, for their vision and their incredibly hard work in ensuring completion of the project. We hope this book will serve you well as an informative and invaluable guide for fracture management in your canine and feline patients.

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This book is dedicated to my husband, Walter E Hoffmann, and my son, Wesley J Hoffmann whose unfailing support allowed me to contribute to the development of this book.

Ann L Johnson

I dedicate this book to my children, Adam John Freeman and Frances Ruth, and to my wife, Sue.

John EF Houlton

Introduction—AO philosophy and principles

Introduction—AO philosophy and principles

1 AO philosophy

The philosophy of the AO group has remained consistent and clear, from its inception by a small group of friends and colleagues in 1958 to its current status as a worldwide surgical and scientific foundation. Seeing as its central concern all patients with skeletal injuries and related problems, the philosophy has been directed to providing for them a pattern of care designed to bring an early return to mobility and function. This philosophy has driven everything that has grown from the original aspirations and plans of the founding group, and remains the central inspiration of today's AO Foundation.

The key to its implementation has been effective and rational management of injured bones and soft tissues so as to foster rapid restoration of the patient's function. Management protocols have constantly been adapted to take account of the fresh understanding of the healing process gained from growing clinical expertise and expanding research.

2 Background

In the first half of the 20th century, fracture management was concentrated on the restoration of bony union, to the exclusion, largely, of other considerations seen today not only as relevant but essential.

The methods employed to manage fractures, mostly by immobilization in plaster or by traction, had the effect, too often, of inhibiting rather than promoting function throughout the healing period, which was itself frequently prolonged. The key concept of the AO was to give expression to its philosophy by safe and effective open reduction and internal fixation of fractures, intimately combined with early functional rehabilitation.

Long before the establishment of the AO, there had, of course, been keen championship and authoritative recognition of the value of open reduction and fixation of fractures. The innovative approaches and technical vision of early advocates of surgical fracture care are well documented. That their ideas were either not heard or failed to penetrate shows how arid was the ground on which these pioneering seeds first fell and, equally, what great technical and biological obstacles remained to be overcome. The list is formidable: infection, dubious metallurgy, poor biological awareness, ill-conceived implants, and an underdeveloped understanding of the role of fixation were all added to peer group skepticism often amounting to real hostility.

Thus, such highlights as the visionary innovations of the Lambottes, the technical achievements of Küntscher with the intramedullary nail, and the conceptual advances of Lucas-Championnière and his protagonist Perkins in introducing early motion (albeit on traction), were dimmed by an apparent inability to reconcile within one pattern of care the two concepts of effective splintage of the fracture and controlled mobility of the joints.

3 The role of the AO

What was needed—and what the AO provided—was a coordinated approach to identify these obstacles, to study the difficulties they caused, and to set about overcoming them. The chosen path was to investigate and understand the relevant biology, to develop appropriate technology and techniques, to document the outcomes and react to the findings, and, through teaching and writing, to share whatever was discovered.

This enormous challenge had an apparently small beginning. In the 1940s and 1950s, questions were being asked, not least by the Swiss state and commercial insurance companies, as to why, if it took some fractures 6–12 weeks to heal, it often took 6–12 months for the patients to return to work.

The story of how an encounter with Robert Danis, first through his writings and later by a personal visit, provided the inspiration for Maurice Müller and the group he subsequently gathered about him to begin developing answers to questions, has been well documented.

The essence of Danis' observation was that if he used a compression device to impart absolute stability to a diaphyseal fracture, healing without callus would take place and, while it was happening, the adjacent joints and muscles could safely and painlessly be exercised.

Inspired by this concept and driven by a determination not only to apply it but also to establish how and why it worked, Müller and the AO group set in train a process of surgical innovation, technical development, basic research, and clinical documentation. This progressed as an integrated campaign to improve the results and minimize the problems of fracture care. They then set about propagating their message by writing and teaching. That work continues to this day, with involvement of many specialist groups working mostly, it should be said, in harmony to the common end of improving patient care worldwide, in greatly differing environments.

4 AO principles

Today, any statement of the key concepts—conventionally referred to as the AO "principles"—through which the AO philosophy was given expression, can be remarkably similar in wording to what appeared in the early AO publications from 1962 onwards. The essential feature, now as then, is the proper management of the fracture within the environment of the patient. The need was for a proper understanding of the "personalities" of the fracture and of the injury; from this all else would follow.

The original management objectives were restoration of anatomy, establishment of stability, while preserving blood supply, with early mobilization of limb and patient. These were at first presented as the fundamentals of good internal fixation. However, with increased understanding of how fractures heal, with acceptance of the supreme role of the soft tissues and with ever-expanding understanding of how implants and bones interact, they have undergone certain conceptual and technological changes while gaining their present status as the principles not just of internal fixation but also of fracture management overall.

Central to the effective application of the AO's concepts was the understanding that articular fractures and diaphyseal fractures have very different biological requirements. Allied to this was the increasingly clear recognition that the type and timing of surgical intervention must be guided by the degree of injury to the soft-tissue envelope and the physiological demands of the patient.

5 Progress and development

The AO principles relating to anatomy, stability, biology, and mobilization still stand as fundamentals. How they have been expressed, interpreted, and applied over the past 40 years has gradually changed in response to the knowledge and understanding emerging from scientific studies and clinical observation.

It is now accepted that the pursuit of absolute stability, originally proposed for almost all fractures, is mandatory only for joint and certain related fractures, and then only when it can be obtained without damage to blood supply and soft tissues. Within the diaphysis, there must always be respect for length, alignment, and rotation. When fixation is required, splintage by a nail is usually selected and this leads to union by callus. Even when the clinical situation favors the use of a plate, proper planning and the current techniques for minimal access and fixation have been designed to minimize any insult to the blood supply of the bony fragments and soft tissues.

It must be appreciated that simple diaphyseal fractures react differently to plating and to nailing, and if plating is employed, absolute stability must be achieved. In contrast, multifragmentary fractures can all be treated by splintage. Fractures of the forearm diaphyses, where long-bone morphology is combined with quasi-articular functions, need special consideration. Articular fractures demand anatomical reduction and absolute stability to enhance the healing of articular cartilage and make early motion possible, which is necessary for good ultimate function.

The imperatives of soft-tissue care, originally expressed in the principle of preserving blood supply to bone, must be addressed in every phase of fracture management, from initial planning to how, if at all, the bone is to be handled. A clear understanding of the roles of direct and indirect reduction, together with informed assessment of how the fracture pattern and soft-tissue injuries relate to each other, will lead to correct decisions on strategy and tactics being made and incorporated into the preoperative plan. From this will follow the choice of implant compatible with the biological and functional demands of the fracture.

6 Philosophy and principles today

In earlier days, the AO principles appeared in a succinct, even dogmatic format. Thus expressed, they transformed not just internal fixation, but fracture management overall. Fracture care became a structured process, rooted in good science and technology and nourished by research and documented studies.

The importance of and the need for fracture fixation in such difficult situations as infection, joint injuries, and polytrauma has been validated and applied to patient care.

These same AO principles are here set out in a form believed to be valid today.

AO principles

1. Fracture reduction and fixation to restore anatomical relationships.
2. Stability by fixation or splintage, as the personality of the fracture and the injury requires.
3. Preservation of the blood supply to soft tissues and bone by careful handling and gentle reduction techniques.
4. Early and safe mobilization of the part and the patient.

These still embody the AO philosophy of patient care and they can still be quite briefly stated.

The continuing study of how the trauma patient's tissues and psyche respond to injury and its management brings the encouraging conviction that when the next formal restatement of the principles comes to be made, the knowledge and understanding on which they are based will once again have been expanded for the benefit of those to whom they are applied and those who apply them alike.

7 Suggestions for further reading

1. **Lucas-Championnière J** (1907) Les dangers de l'immobilisation des membres—fragilité des os—altérnation de la nutrition de la membre—conclusions pratiques. *Rev Med Chur Pratique*; 78:81–87.
2. **Müller ME, Allgöwer M, Willenegger H** (1965) *Technique of Internal Fixation of Fractures.* Berlin Heidelberg New York: Springer-Verlag.
3. **Schatzker J** (1998) M. E. Müller—on his 80th birthday. *AO Dialogue*; 11(1):7–12.

1 Perioperative patient management

Authors John EF Houlton, Dianne Dunning

1 Perioperative patient management

1 Introduction

Musculoskeletal injuries are commonly associated with concurrent trauma to other organ systems. Therefore it is important to focus on the patient as a whole and adhere to a treatment paradigm of providing life support prior to considering the orthopedic injury. Once the patient has been thoroughly assessed and stabilized, the fracture may be addressed and pain management instituted. Understanding the AO fracture classification system will facilitate fracture repair planning and minimize intraoperative time. Furthermore, patient complications may be avoided by strict adherence to proper preoperative assessment and preparation, surgical asepsis, and atraumatic fracture reduction techniques. Postoperatively, it is important to evaluate the fracture fixation radiographically for reduction, stability, and joint alignment. Finally, it is important to provide supportive care and early active rehabilitation to avoid the detrimental effects associated with musculoskeletal trauma and prolonged immobilization, and to encourage early return of limb function.

2 Preoperative management of the trauma patient

When presented with an animal with an appendicular fracture, it is tempting to treat the fracture and disregard the patient as a whole. **Musculoskeletal injuries frequently occur in association with injury to other vital organs and, therefore, must be considered in the context of polytrauma. Precedence must be given to the ABCD of triage prior to assessing and/or treating any orthopedic injury.**

ABCD triage:
A = airway
B = breathing
C = circulatory
D = other disabilities

Patient assessment and triage is used to define and treat the most life-threatening injuries. Initial management of the trauma patient includes a primary survey of the animal and intervention as necessary. Recording vital signs should be performed as a first priority, to establish a baseline for treatment. In addition, blood and urine samples should be obtained and submitted for an emergency minimum database. Life-saving procedures receive precedence in patient stabilization, following a systematic approach to the ABCD of triage [1, 2].

Airway patency is evaluated by looking in the oral cavity and pharynx for signs of obstruction from blood, debris, or foreign material. Supplemental oxygen is indicated provided its administration does not cause additional distress. Oxygen may be administered via face mask, nasal insufflation, oxygen cage or flow-by technique (direct administration by holding the oxygen tubing in front of the animal's nares). **Breathing** is assessed by observation and auscultation. The thoracic wall should be palpated to detect fractured ribs or subcutaneous emphysema, which may point to thoracic wall trauma or pneumothorax. Oxygen saturation may be assessed by pulse oximetry.

Evaluate and treat the patient before concentrating on treating the fracture.

Dyspneic animals should undergo thoracocentesis for pneumo- or hemothorax. **Circulatory** function is assessed by evaluating heart rate, rhythm, EKG, pulse character, mucous membrane color, and capillary refill time. Establish vascular access with an intravenous catheter and treat hypovolemic shock with crystalloid fluids. If the hemodynamic status of the patient is not improved by crystalloid therapy, consider colloid or blood product supplementation. Once stabilized, a second survey of the patient should be performed to reassess and treat additional injuries **(disability)**. **A complete physical, orthopedic, and neurological examination is indicated prior to definitive care of the musculoskeletal injury** [3]. This examination will include appropriate diagnostic imaging techniques such as radiography and ultrasonography, supported by laboratory tests as necessary.

Assess the fracture and the surrounding soft tissue to accurately evaluate the injury.

The specific components of an emergency minimum database will vary with each clinician and individual case. Many clinicians obtain a packed cell volume (PCV), total solids (protein), blood glucose, blood urea nitrogen, activated clotting time and urine specific gravity while awaiting full blood work analysis. Baseline blood work parameters should be evaluated in each trauma patient to detect preexisting disease. For the first 24–72 hours, these parameters should be monitored for changes. **Thoracic and abdominal radiographs should be evaluated in all animals with external traumatic injuries before definitive therapy is instituted.**

Cover open fractures immediately.

When assessing musculoskeletal injuries it is important to evaluate not only the fracture, but also the associated soft-tissue damage. **The extent of soft-tissue trauma, the presence of embedded foreign debris, damage to the underlying neurovascular structure, and the depth and width of wounds all play a role in determining treatment options and functional outcome.** It is important to recognize that the zone of soft-tissue injury often extends beyond the area of the fracture site and the magnitude of injury depends on the tissue type and amount of force applied [1, 4]. The neurological and circulatory status of the affected limb should be assessed for sensation and vascular integrity by evaluating voluntary motor and sensory function, skin perfusion, and peripheral pulses. Doppler ultrasound is a simple noninvasive method for determining tissue viability [5].

Only debride obviously necrotic tissue. Use wet-to-dry dressings for continued debridement.

Open fractures should be immediately covered with a sterile dressing and the limb splinted to prevent further soft-tissue damage. Once the animal is stabilized, it may be anesthetized for wound exploration, lavage, and debridement. Surgical preparation and an aseptic technique should be employed in order to prevent further contamination. **Completely debride obviously necrotic and avascular tissue, remove dirt and foreign debris, and copiously lavage the remaining soft tissues and bone.** Obtain a deep swab of the wound for culture and sensitivity. Apply an adherent wet-to-dry bandage to the wound for further debridement and externally coapt the limb as with a closed fracture.

Soft-tissue injuries associated with open fractures are rarely sutured as infection is a common complication of premature wound closure. Superficial wounds may be treated postoperatively with wet-to-dry dressings changed daily to further debride nonviable tissue. Healthy granulation tissue will appear on the wound surface within 1–2 weeks. Nonadherent bandages should be employed once granulation tissue appears. If devascularized bone is visible in the wound it must be excised as a part of the debridement process. Contraction of the wound will eventually occur, with fibrous scar tissue covering the remaining exposed surface. Skin grafts may be required to speed healing and improve cosmesis after granulation tissue has been established. On occasions these are important from a functional aspect, especially where wounds are adjacent to joints.

The management of closed fractures is relatively less complicated. Prior to surgery, the joints should be realigned and the limb immobilized in as normal a position as possible. **Fractures below the elbow and stifle should be supported by a Robert Jones bandage, or by a modified Robert Jones bandage with palmar or lateral splints.** Above the elbow and stifle, a spica splint may sometimes be applied; however, strict cage confinement is also acceptable for some upper limb fractures. Fractures of the skull, maxilla, spine, and pelvis will be addressed separately in later chapters.

Prior to surgery, take a radiograph of the fractured extremity. A minimum of two orthogonal views is required to assess the fracture accurately and to select the best method of fixation. **Stress radiographs are indicated if joint instability is suspected. Occasionally, oblique views are necessary, particularly where fractures involve composite joints such as the carpus and tarsus. Radiographs of the contralateral intact bone can serve as a template for fracture reduction and are indicated in articular fractures and fractures of curved bones that can be anatomically reduced.** A complete radiological assessment of the surgical patient will reduce intraoperative errors and overall procedure time. Fracture classification can be determined together with an estimation of the soft-tissue injury, thereby defining the surgical strategy and execution.

Finally, clear client communication is essential [6]. The decision to operate and choice of the procedure should be agreed with the client. **The advantages and risk factors of each procedure should be clearly and concisely discussed, and informed owner consent obtained prior to entering the operating room.**

Avoid premature wound closure as infection and wound dehiscence is a common complication.

Always obtain two radiographic views of the fractured bone to completely evaluate the fracture and plan the repair. In some cases, views of the contralateral bone are indicated to aid in fracture treatment planning.

3 Pain management

Pain management is essential to reduce anxiety, decrease stress and its associated hormonal and metabolic derangements, and to allow the patient to rest comfortably.

Assessing pain in the veterinary patient can be difficult. Common behavioral signs indicative of pain include vocalization, postural changes, trembling, restlessness, depression, disrupted sleep cycles, inappetence, aggression, and agitation [7–10]. Common physiological parameters include tachypnea, tachycardia, hypertension, dilated pupils, and ptyalism [7–10]. **All trauma and surgical patients benefit from pain management** [7–10]. Most orthopedic procedures and fracture repair are considered moderately to severely painful [7–10]. Effective pain management reduces anxiety, decreases stress and its associated hormonal and metabolic derangements, and allows the patient to rest comfortably.

Analgesics are most effective when administered prior to the onset of pain.

Clinical and experimental studies clearly indicate that **analgesics are most effective when administered prior to the onset of pain, as surgery or any noxious insult alters how the nervous system both processes and responds to stimuli** [7, 9]. This phenomenon is called sensitization and it affects the nervous system at the peripheral and central levels [7, 9]. Peripherally, nociceptor afferent fibers display a reduced threshold for stimulation [7, 9]. Centrally, the neurons in the dorsal horn of the spinal cord experience an increase in activity and excitation. In concert, these changes lead to postinjury pain hypersensitivity both at the site of injury and in the surrounding tissues [7, 9]. **Common agents used as preemptive analgesics include opioids, nonsteroidal antiinflammatory drugs (NSAIDs), and local anesthetics** [10]. Opioids act at both peripheral and central sites to reduce afferent nociceptive transmission and alter spinal pathways [7, 9]. NSAIDs reduce peripheral nociceptor activity and may have a central analgesic action as well [11]. Local anesthetics act peripherally to prevent the transduction of noxious stimulus to the dorsal horn of the spinal cord [7, 9]. Other less commonly employed analgesic adjunctive agents include α_2-adrenergic agonists, n-methyl-d-aspartate (NMDA) antagonists (eg, ketamine), and corticosteroids [12].

Multimodal or multiple agent analgesia is preferred as it results in a synergistic analgesic effect.

Orthopedic pain may be managed with single or multimodal analgesia (**Table 1-1, Table 1-2**). Single agent analgesia involves the administration of a lone drug agent, whereas multimodal analgesia is the administration of a combination of different classes of analgesic drugs to achieve optimal pain control [11, 13–15]. **The advantage of multimodal analgesia over single-drug analgesia is that it selectively targets several sites along the pain pathway, resulting in an additive or synergistic analgesic effect, and dosages of individual drugs can typically be reduced** [10, 11, 13, 14]. When used preemptively, multimodal analgesia helps to inhibit surgery-induced sensitization, minimizes development of drug tolerance, and suppresses the neuroendocrine stress response to pain and injury. It shortens the recovery time through improved tissue healing, maintenance of immune responses, and better patient mobility [11, 13, 14].

Injectable, transdermal, and oral routes of administration are all effective means of drug delivery when properly employed. Injectable drugs may be delivered via a fixed dosing interval or continuous rate infusion (CRI). **CRI is an ideal way to administer narcotics during the postoperative period.** It is safe, inexpensive, and maintains a constant plasma level of a drug thereby eliminating periods of diminishing analgesia that invariably occur with intermittent bolus administration [7, 9]. In addition, the dose can be more precisely

Table 1-1 Multimodal analgesic drug dosages for the dog.

Analgesic class	Drug	Dose
Opioids	Morphine	• 0.5–1.0 mg/kg IV q 1–2 h • 0.2–2.0 mg/kg IM, SQ q 2–6 h • 0.3–0.5 mg/kg IV loading dose followed by 0.1–0.3 mg/kg/h IV CRI
	Oxymorphone	• 0.02–0.1 mg/kg IV q 1–2 h • 0.05–0.2 mg/kg IM,SQ q 2–4 h
	Fentanyl	• 0.002–0.003 mg/kg IV loading dose followed by 0.001–0.005 mg/kg/h IV, CRI
	Hydromorphone	• 0.05–0.2 mg/kg IV, SQ, IM q 4–6 h
	Buprenorphine	• 0.005–0.015 mg/kg IV, IM q 4–8 h
Adjunct analgesics		
α_2-adrenergic agonists	Xylazine	• 0.2–2.0 mg/kg
	Medetomidine	• 5–30 μg/kg
NMDA receptor antagonist	Ketamine	• 0.5–1.5 mg/kg/h IV, CRI
Local anesthetic	Lidocaine	• 1.0–3.0 mg/kg/h IV, CRI
Tranquillizers	Acepromazine	• 0.2–0.1 mg/kg IV, IM, SQ
	Diazepam	• 0.2–0.4 mg/kg IV, IM
	Midazolam	• 0.2–0.4 mg/kg IV, IM
NSAIDs	Carprofen	• 2.2 mg/kg PO bid for the first two weeks, then qd as needed for pain
	Etodolac	• 10–15 mg/kg PO qd
	Deracoxib	• 3–4 mg/kg/day for 7 days for acute postoperative pain management • 1–2 mg/kg/day for extended use
	Meloxicam	• 0.2 mg/kg IV, SQ • 0.1 mg/kg PO for extended use
	Quadrisol	• 0.5 mg/kg PO qd
	Zubrin	• 10 mg/kg PO qd

Table 1-2 Analgesic drugs and dosages for the cat.

Analgesic class	Drug	Dose
Opioids	Morphine	• 0.05–0.1 mg/kg IM, SQ q 3–4 h • 0.08–0.1 mg/kg loading dose followed by 0.05–0.1 mg/kg/h IV, CRI
	Oxymorphone	• 0.02–0.05 mg/kg IV q 1–2 h • 0.05–0.1 mg/kg IM, SQ q 2–4 h
	Fentanyl	• 0.002–0.003 mg/kg/h IV loading dose followed by 0.001–0.005 mg/kg/h IV, CRI
	Hydromorphone	• 0.05–0.1 mg/kg IV, IM q 2–4 h
	Buprenorphine	• 0.005–0.01 mg/kg IV, IM q 3–8 h
Adjunct analgesics		
α_2-adrenergic agonists	Xylazine	• 0.2–2.0 mg/kg
	Medetomidine	• 5–30 μg/kg
NMDA receptor antagonist	Ketamine	• 0.5–1.5 mg/kg/h IV CRI
Local anesthetic	Lidocaine	• 1.0–3.0 mg/kg/h IV, CRI
Tranquillizers	Acepromazine	• 0.2–0.1 mg/kg IV, IM, SQ
	Diazepam	• 0.2–0.4 mg/kg IV, IM
	Midazolam	• 0.2–0.4 mg/kg IV, IM
NSAIDs	Ketoprofen	• 1.0–2.0 mg/kg once after surgery, then 0.5–1.0 mg/kg for up to 3–5 days IV, IM, PO
	Carprofen	• 1.0 mg/kg PO once only

IV = intravenous
IM = intramuscular
SQ = subcutaneous
CRI = continuous rate infusion
PO = orally
q = every
qd = daily
qod = every other day
bid = twice a day

When choosing any drug, due attention must be paid to any relevant local prescribing regulations.

titrated to achieve the desired analgesic effect without precipitating adverse side effects [7, 9]. If CRI is not an option, a fixed dosing interval for opioid administration should be utilized during the first 24–48 hours [7, 9]. The traditional approach of waiting for the animal to show pain before implementing pain relief should be avoided at all costs. Opioids (fentanyl, morphine, and pethidine) are the most common drugs used as CRI agents. However, NMDA antagonists (ketamine) and local anesthetics (lidocaine) are also gaining in popularity as adjunctive analgesics [16].

Do not wait for the patient to show pain, instead implement pain relief routinely.

Transdermal administration of opioids is easy, convenient, and provides a reasonable alternative to CRI. Fentanyl patches must be applied 12–24 hours prior to surgery to reach therapeutic plasma concentration [7, 9]. It is important to handle the patch carefully and apply it to a clean, dry, defatted area of skin that cannot be easily reached by the patient for predictable transdermal absorption [7, 9]. Unlike CRI administration, however, the patch cannot be modified or manipulated to change the dose delivered, so patients must be monitored closely to assess if supplemental analgesia is needed [7, 9].

Methods of administering pain medication include injection or continuous rate infusion, transdermal administration, and oral administration of appropriate drugs.

Oral administration of analgesics plays a significant role in the multimodal management of orthopedic pain. NSAIDs are the most commonly used oral drugs, but they should never be used as a single analgesic agent except in the case of minor orthopedic procedures such as implant removal or bone biopsy [11]. NSAIDs are most efficacious when administered 12–24 hours prior to surgery. Patients should be screened carefully prior to their use, particularly where there is a significant risk of gastrointestinal ulceration, renal disease, or coagulopathy. For most healthy orthopedic patients, the benefits of NSAIDs outweigh the risks of drug-induced complications [11]. However, cyclooxygenase 2 (COX-2) inhibitors should not be used in the management of chronic post-fracture repair pain since they may have an inhibitory effect on bone healing [17].

4 Sedation and anesthesia

Sedation may be required to immobilize the orthopedic patient during physical and radiographic examinations and for extensive postoperative bandage changes. Common agents used as sedatives include neuroleptanalgesic and α_2-adrenergic-agonist agents. Neuroleptanalgesia is produced by the combination of a neuroleptic drug (acepromazine) and an analgesic drug (usually an opioid) and induces a state of hypnosis and analgesia which is useful in reducing pain and anxiety associated with minor diagnostic and therapeutic procedures [12, 14]. α_2-adrenergic-agonists are classified as sedative-analgesic and are also popular for chemical restraint in young, healthy orthopedic patients as they produce good muscle relaxation, are easily reversible, and can be combined with opioids for additional analgesia [7–9, 12, 14]. However, dogs and cats with suspected cardiac dysfunction should not be given α_2-adrenergic-agonists due to the increased vascular resistance and cardiac afterload [18].

Most orthopedic procedures require a balanced anesthetic protocol due to their high level of surgical stimulation. Commonly used anesthetic protocols for fracture repair include analgesic premedication, injectable induction agents, and inhaled gases for the maintenance of an even anesthetic plane. Drug combinations frequently used in the preanesthetic period include acepromazine and an opioid (morphine, oxymorphone, hydromorphone, pethidine, fentanyl, meperidine, butorphanol, or buprenorphine). Alternatively an α_2-adrenergic-agonist (medetomidine, xylazine) and an opioid (same as above), or a benzodiazepine (diazepam or midazolam) and an opioid (as above) may be used [12, 14]. Additionally, a combination of opioids (morphine or fentanyl) and ketamine or lidocaine can be administered as a continuous rate infusion intraoperatively. They may be continued postoperatively, as necessary, for supplemental analgesia [12, 14]. **Local and regional anesthetics and analgesics (such as epidural analgesia, peripheral nerve blocks, surgery site infiltration, brachial plexus blocks, and intraarticular blocks) will decrease the intraoperative pain response, provide good muscle relaxation, and attenuate autonomic and endocrine responses to surgery** [19, 20]. NSAIDs can also be administered with the above combinations 12–24 hours prior to surgery for improved postoperative comfort [11].

Sedate animals for easier physical and radiographic examinations and for extensive postoperative bandage changes.

Balanced anesthesia includes analgesic premedication, injectable induction, inhaled gases, as well as local and regional anesthetics. It provides excellent anesthesia, analgesia, and muscle relaxation during fracture treatment.

5 Antimicrobial therapy

Staphylococcus intermedius originating from the skin causes the majority of orthopedic infections.

The infection rate of elective orthopedic surgery is reported to be between 2.5 and 4.8% [21–24]. The majority of orthopedic infections are caused by Staphylococcus intermedius originating from the skin [25]. Known host risk factors for infection in the small animal surgical patient include the age of the patient (> 8 years), the presence of distant sites of infection, obesity, a preexisting endocrinopathy, and prior irradiation of the surgical site [21, 23, 26]. Reported intraoperative risk factors for infection are preclipping the limb prior to anesthetic induction, inadequate skin preparation of the surgical site, prolonged anesthetic episode, and administration of propofol as a part of the anesthetic protocol [23, 27–29]. Intraoperative factors potentiating wound infection include duration of surgery (> 90 minutes), excessive use of electrocautery, a break in surgical asepsis, use of braided or multifilament suture material, and large orthopedic implants within the wound [27].

Perioperative antibiotic administration consists of intravenous injection of antimicrobials 30 minutes prior to incision followed by additional injections of antibiotic during the surgical procedure.

Perioperative antimicrobial prophylaxis may be defined as the administration of an antimicrobial agent prior to a surgical incision [22, 30, 31]. Antimicrobial therapy is routinely employed for perioperative prophylaxis in most orthopedic surgeries, even though the majority of orthopedic procedures are defined as clean. Clinical studies demonstrate a four-fold reduction in the rate of infection when antimicrobial prophylaxis is appropriately employed during clean orthopedic procedures [22]. **Traditionally, perioperative antimicrobial prophylaxis is not recommended in clean procedures except when the procedure time exceeds 90 minutes, metallic implants are used, or extensive soft-tissue injury is present** [22, 30, 31].

Antibiotics should be selected in anticipation of the usual contaminating bacteria. The ideal antimicrobial agent should be bactericidal, have a low toxicity, be cost effective and be parenterally administered [32, 33]. Accordingly, **cefazolin is the antimicrobial of choice of most veterinary surgeons.** Other acceptable alternatives include semisynthetic β-lactam-resistant penicillins and clindamycin.

For an antimicrobial to be effective it must be present within the tissue at maximal therapeutic concentrations at the time of contamination (or at the time of incision) [34]. Experimental studies demonstrate that there is no effect if the antimicrobials are administered after the contamination has begun. If given intravenously, the antimicrobial should be given at least 30 minutes prior to the surgical incision (but not more than 60 minutes) to achieve adequate tissue concentration at the time of surgery [35]. This recommendation is based on evidence that peak serum and surgical wound fluid concentrations take approximately 30 minutes to equilibrate, and then subsequently rapidly decline [35]. Antimicrobials administered 3 hours after bacterial contamination have proven to be of no benefit in controlling wound infection [36, 37]. Redosing should be based on the known pharmacokinetic behavior of the drug and the time during which adequate concentrations are required [36–40].

6 Fracture classification

Appendicular fractures may be classified on the basis of location, reducibility, direction, number of fracture lines, stability after anatomical reconstruction, and whether they communicate with the outside environment [41, 42]. AO Vet has adapted a fracture classification system from humans, which accommodates the special requirements of small animals (**Fig 1-1**) [41, 42]. The localization and morphology of fractures are characterized and defined with conventional terms and assigned an alphanumerical code to allow easy computer accessed data retrieval [41, 42].

Each long bone is assigned a number (1 = humerus; 2 = radius/ulna; 3 = femur; 4 = tibia/fibula) and is further divided into three zones (1 = proximal; 2 = shaft; 3 = distal) [41, 42]. Each fracture is additionally typed according to severity (A = single fracture; B = wedge or butterfly fragment; C = complex or more than one fragment) [41, 42].

Open fractures

Open fractures are classified by origin and degree of soft-tissue injury (**Table 1-3**). The purpose of this classification system is to alert the surgeon to the complexity and magnitude of possible soft-tissue problems.

A **type I** open fracture is caused by the bone penetrating through the skin and is characterized by a small puncture hole located in the skin in the proximity of the fracture [38–40]. Depending upon the amount of soft-tissue coverage, the bone may or may not be visible in the wound.

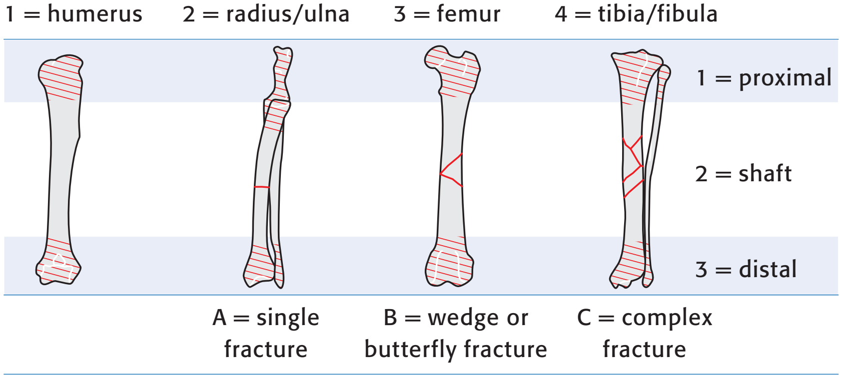


Fig 1-1 Alphanumerical coding system for fracture diagnosis.

Fracture classification	Description
Type I	Open fracture Small laceration (< 1 cm) Clean
Type II	Open fracture Larger laceration (> 1 cm) Mild soft-tissue trauma No flaps or avulsions
Type III(a)	Open fracture Vast soft-tissue laceration or flaps or high-energy trauma Soft tissue available for wound coverage
Type III(b)	Open fracture Extensive soft-tissue injury loss Bone exposure present Periosteum stripped away from bone
Type III(c)	Open fracture Arterial supply to the distal limb damaged ± Arterial repair required for limb salvage

Table 1-3 System for classification of open fractures. The grading system is based on the degree of soft-tissue injury irrespective of the underlying fracture. The prognosis worsens as the grade becomes higher. Adapted with permission from Tillson DM (1995) Open fracture management. *Vet Clin North Am;* 25(5):1094.

A **type II** open fracture also has a skin wound that communicates with the fracture, but, in contrast, the soft-tissue injury is generally more extensive and is a direct result of external trauma [38–40]. Despite the greater extent of soft-tissue injury, a grade II open fracture is usually simple or minimally comminuted.

Type III open fractures are characterized by severe comminution and extensive soft-tissue injury with variable skin loss (subclassification a–c) [38–40]. These fractures are usually the result of high-energy trauma such as gunshot injuries or shear type injuries of the distal extremities associated with vehicular trauma.

Physeal fractures

Physeal fractures are classified by the Salter-Harris classification system (I–VI), which describes the fracture location with reference to the growth plate (**Fig 1-2**) [43, 44].

Salter-Harris type I fractures run through the physis [43, 44].

Salter-Harris type II fractures run through the physis and a portion of the metaphysis [43, 44].

Salter-Harris type III fractures run through the physis and the epiphysis, and are generally intra-articular fractures [43, 44].

Salter-Harris type IV fractures are also articular fractures, running through the epiphysis, across the physis, and through the metaphysis [43, 44].

Salter-Harris type V fractures are a crushing of the physis which is not visible radiographically, but is evident several weeks later when physeal growth ceases [43, 44].

Salter-Harris type VI fractures are characterized by a partial physeal closure resulting from damage to a portion of the physis [43, 44].

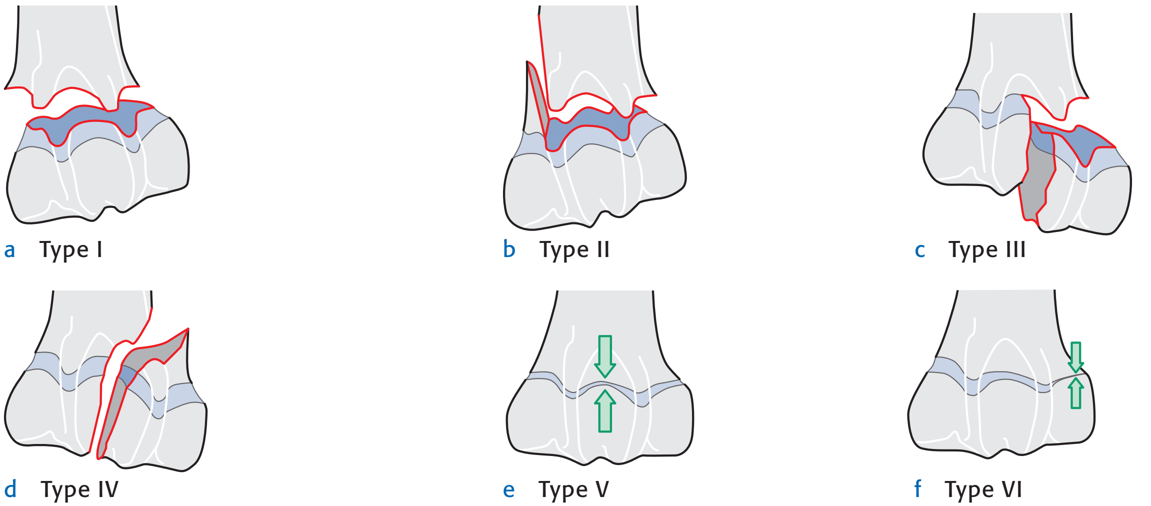


Fig 1-2 Examples of physeal injuries (classified after Salter and Harris).

7 Fracture treatment planning and decision making

The main objective of the treatment of any fracture is the early return of the patient to full function. The key to achieving this goal is the detailed planning of the entire surgical procedure and postoperative care. **Failure to plan and anticipate problems associated with fracture repair consistently results in prolonged operating time, excessive soft-tissue trauma, and technical errors.** An ill-prepared surgeon will invariably experience a higher complication rate due to infection, implant failure, delayed healing, and nonunion.

Patient considerations, such as age, weight, the presence of concurrent injuries and its overall general health, the expected activity level and intended use of the animal, and the ability of the owner to perform postoperative care should all be carefully considered when choosing the method of fracture repair. In addition, the fracture must be evaluated to determine the mechanical forces acting on the bone as well as the biological effects of the fixation in light of the trauma. **Orthogonal views of the affected bone including the proximal and distal joints are mandatory in the full analysis of the fracture. Radiographs of the contralateral limb should be considered when evaluating articular and complex fractures of curved bones.**

In considering the fracture, the surgeon must ascertain whether full reconstruction of the bone column is possible (**Table 1-4**) [45]. Restoration of the bone permits sharing of the weight-bearing load with the implant and will protect the implant from fatigue and early failure. An unreconstructed fracture relies solely on the implant to sustain axial loading. This may be preferred in cases with extensive soft-tissue injuries or grade III open fractures, but implants bearing the majority of the load in an unfavorable mechanical environment must be larger, stronger, and more stable for extended periods of time. Animals with polytrauma or multiple orthopedic injuries will place greater demands on implants as they may be forced, prematurely, to take weight on an injured limb.

Patient considerations may dictate the method of fracture repair.

The biological environment of the fracture must also be taken into consideration. Young animals with an active periosteum, and metaphyseal fractures with an abundance of cancellous bone, are quick to heal in most situations. Conversely, comminuted high-energy fractures may have impaired vascularity and thus longer healing times can be anticipated. Geriatric or debilitated animals, or animals that have sustained substantial soft-tissue injury, will experience prolonged healing times which necessitate the need for stable implants for extended periods of time.

Mechanical factors such as fracture configuration, potential for reconstruction and presence of concurrent musculoskeletal injuries affect the load the implant will bear.

Once information regarding the patient has been obtained and the mechanical and biological environment of the fracture is known, a decision regarding the appropriate type of fixation may be made.

Biological factors such as age, fracture location, and soft-tissue injury affect the length of time an implant must function.

Anatomical reconstruction	Major segment alignment
• Articular fractures • Simple fractures • Fractures with two or three large fragments	• Severely comminuted fractures: Treat with plates, plate-rod combinations, locked intramedullary nails, or external fixators.

Table 1-4 Indications for anatomical reduction versus major segment alignment.

Fracture planning checklist:
1. Decide on appropriate fixation based on fracture and patient assessment.
2. Plan fracture reduction.
3. Plan fracture fixation.
4. Select surgical approach(es).
5. Check implant inventory.
6. Perform surgery.
7. Critically evaluate postoperative radiographs.

The surgeon must decide whether open or closed reduction is preferred based upon fracture location and complexity, and the type of fixation selected (**Table 1-5**). Open reduction allows for bone grafting and anatomical reconstruction of articular and comminuted fractures, but it has the disadvantage of prolonging surgery time and impairing blood supply. Closed reduction of fractures preserves the blood supply and biology of the fracture but at the cost of fracture fragment alignment. It should be reserved for minimally displaced or incomplete fractures, or for comminuted fractures treated with external fixation.

Several planning techniques may be employed for fracture fixation, once the type of fracture fixation and method of reduction have been chosen. The first and most simple method is the **direct overlay method**, in which radiographic tracings of the fracture fragments are used to plan the reduction (**Fig 1-3**). Each fracture fragment is individually traced on a separate sheet of tracing paper. The "fracture" is then reduced by laying each of the fracture tracings over a tracing of a straight line along the bone's physiological axes to make a final composite drawing. Anatomically reconstructable diaphyseal fractures of the long bones are generally planned using this method. The appropriate size of implants may then be selected and tested on the reconstructed composite.

The second planning method requires a radiograph of the patient's **intact contralateral bone** (**Fig 1-4**). An outline of the intact contralateral bone is created by inverting or flipping over the craniocaudal radiograph and tracing a template on to tracing paper. Place the tracing of the normal bone over the radiograph of the fracture and align the intact shaft with that of the tracing and trace the most proximal fracture line. Now align the intact edge of the distal fragment with the tracing and trace the fragment line in the reduced position. Repeat these steps until all the fracture lines have been outlined and the fracture has been reconstructed. The appropriately sized implants may then be selected and tested on the reconstructed composite. This fracture planning method is of particular use in articular fractures and fractures of curved bones that can be anatomically reduced.

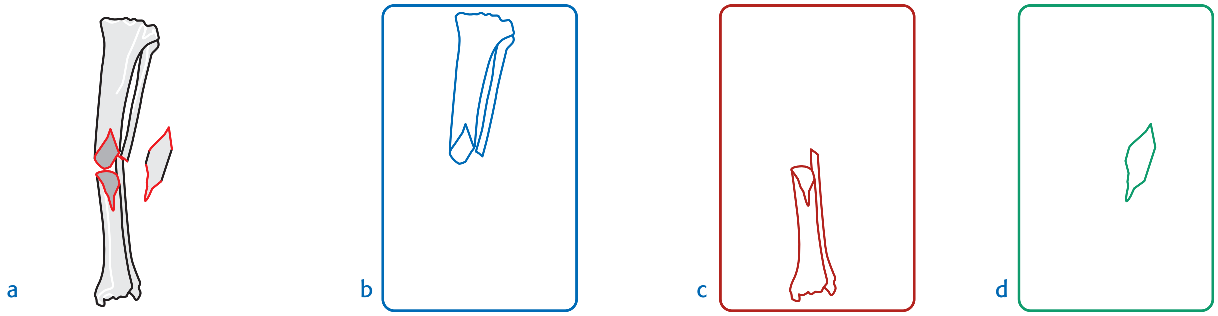
The third planning method uses a **bone specimen** of a similar size animal (**Fig 1-5**). Using the radiographs, the fracture lines are drawn directly onto the bone in the approximate location of the clinical case. The appropriately sized implants may then be selected, contoured, and tested on the specimen. This technique has the advantage that the implant may be precontoured prior to surgery, thus saving valuable intraoperative time.

It is important to **check your implant and instrument inventory**, prior to finalizing the plan. In addition, a thorough review of the relevant anatomy and surgical approach will reduce surgical time and minimize iatrogenic damage.

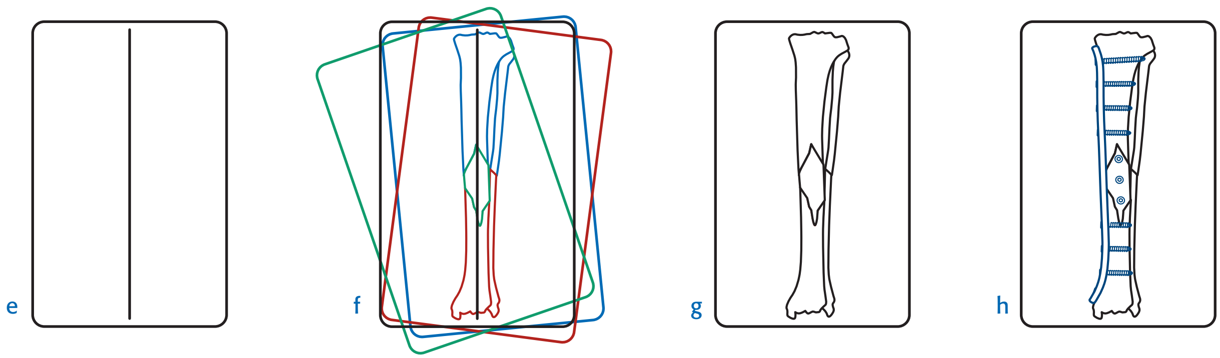
Open reduction	Closed reduction
• Articular fractures	• Nondisplaced or incomplete fractures
• Simple displaced fractures	• Comminuted fractures treated with external fixation
• Comminuted fractures treated by major segment alignment and cancellous bone grafting	

Table 1-5 Indications for open or closed reduction.

Fig 1-3a–h Direct overlay method of fracture fixation.

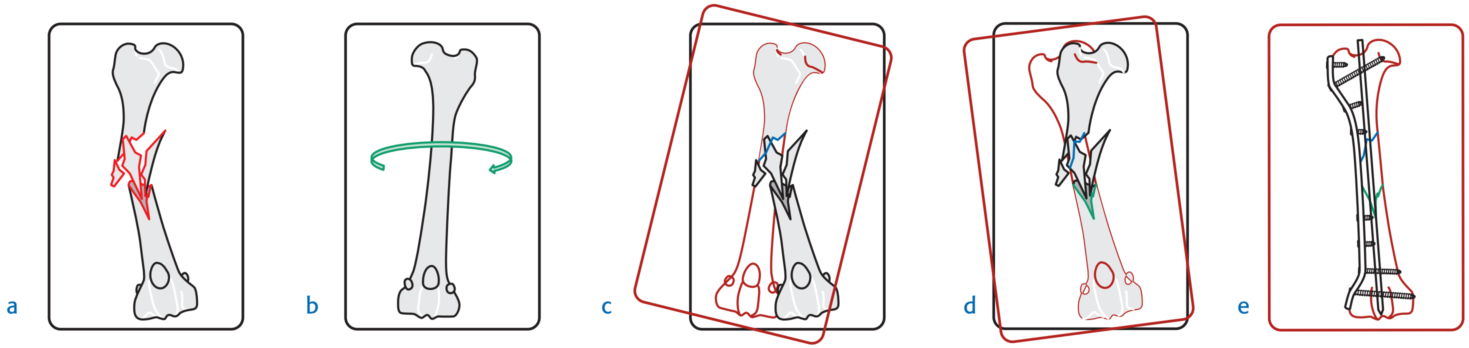


a–d Use preoperative radiographs to trace fracture fragments on three separate transparencies.



e–f On a separate sheet draw a vertical line and reduce the fracture by laying each of the fragment tracings over the straight line drawing to form a composite picture.
g–h Make a final composite drawing. Use the template to test implant configurations.

Fig 1-4a–e Using the patient's intact contralateral bone as a template.



a Take a radiograph of the fractured bone.
b Take a radiograph of the patient's contralateral bone to provide a mirror image of the intact bone. Flip over the radiograph and trace the intact bone to provide an outline which will serve as a template for reducing the fracture through the subsequent steps.
c Place the tracing of the normal side over the craniocaudal view of the fracture. Align the intact shaft of the fracture with the bone shaft of the tracing. Trace the proximal fracture line.
d Align the intact edge of any distal fragment(s) with the same contour on the tracing and trace the fracture line(s).
e Use the template to add the appropriate implants to the composite drawing.

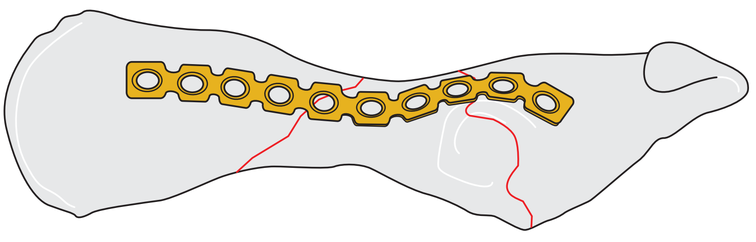


Fig 1-5 Bone specimen.
Draw the fracture lines onto an appropriately sized bone specimen based upon studied analysis of the radiographs. Using the patient's intact bone as a template, decide upon the appropriate implants and contour the plate to the bone specimen, checking the relationship of the implants to the fracture lines.

8 Principles of patient preparation, surgical approaches, and fracture reduction

Patients should be fasted for 6–12 hours and allowed to urinate and defecate prior to anesthetic induction. Water need not be withheld. Following induction, hair is removed from the proposed surgery site with a number 40 clipper blade and vacuum. For most appendicular procedures, all hair should be removed circumferentially from the limb from the carpus or tarsus distally to the dorsal and ventral midline proximally. The foot can be covered with a glove, or gauze and tape, and hung from a drip stand for skin preparation of the surgical site. For orthopedic procedures of the axial skeleton, extend the clipped area liberally past the proposed site of incision for at least 8–10 cm.

A general cleansing agent is used to remove residual hair, dirt, and debris from the proposed surgical site. Commonly used agents include iodophors, chlorhexidine, alcohols, and hexachlorophene. The prepared site is then covered with a sterile drape before transporting the animal into the operating suite.

Correct patient positioning is imperative for adequate exposure and ease of reduction of the fracture. Once properly positioned, the animal is surgically prepped again prior to draping. Standard quadrant and fenestrated draping techniques are used to create a sterile field within which to work. Sterile stockinette or plastic adhesive drapes may be applied to appendicular fractures to reduce skin exposure and contamination.

People entering the operating room should be properly attired in surgical clothing, consisting of scrub top and trousers, caps, masks, and designated shoes or shoe covers. Persons with facial hair should wear hoods. Those undertaking the procedure should remove all jewellery, perform a surgical scrub, and wear a sterile gown and surgical gloves.

The goal of any fracture fixation is to restore limb alignment and to stabilize the fracture. Normal limb alignment is achieved by restoring normal limb length and the spatial orientation of the joints adjacent to the fracture. Fractures may be treated in open or closed fashion. The choice of surgical approach is dictated by the choice of fracture fixation and by the fracture itself. **Closed reduction involves reducing fractures or aligning limbs without surgically exposing the fractured bones.** This approach has several advantages as it preserves the surrounding soft tissues and blood supply to the bone, and decreases the possibility of iatrogenic contamination associated with surgery. The end result is reduced overall operating time, improved healing potential, and a reduced rate of infection. The main disadvantage of closed reduction is that cortical apposition of the fracture fragments is hindered since the fracture fragments cannot be seen. As anatomical fracture reconstruction is impaired, the goals of closed reduction are restoration of bone length and limb alignment. Postoperative radiographs must be carefully examined to ensure normal limb alignment. Fractures repaired with external skeletal fixation are a prime example of closed fixation. Other methods of closed reduction include external coaptation with casts and normograde intramedullary pinning.

Open reduction uses a surgical approach to expose fractured bone segments and fragments, so they can be anatomically reconstructed and held in position with implants. The fracture fragments may be seen and reconstructed and a

A widely clipped and prepared area is necessary for fracture treatment. Also consider preparing an autogenous bone graft donor site.

Generally the surgical site is scrubbed once in the prep room and again after the patient enters the operating room.

Proper surgical attire is mandatory for operating room personnel.

Closed reduction minimizes trauma and preserves the biological environment at the fracture site. It is indicated for both nondisplaced fractures and nonreducible fractures.

Animation

Open reduction allows visualization and reconstruction of fractures. It is indicated for anatomical alignment and stabilization of reducible fractures.

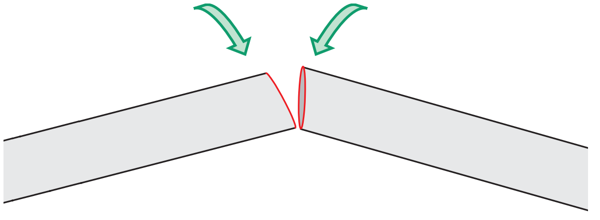


Fig | Anim 1-6

Animation

The decision to perform open or closed fracture reduction depends on fracture configuration and location, as well as on types of implants used for fracture stabilization.

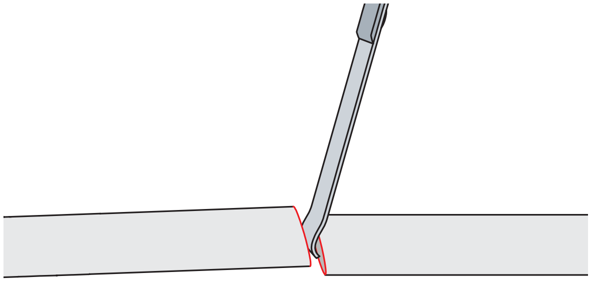


Fig | Anim 1-7

Animation

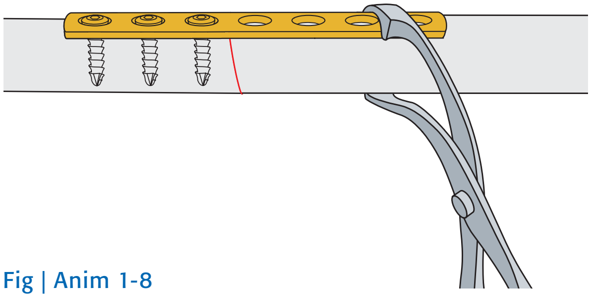


Fig | Anim 1-8

cancellous bone graft can be used to enhance bone healing. The major benefit of a fully reconstructed bone column is that it can share in the weight-bearing load of the limb during fracture healing. Therefore, open fracture fixation is reserved for fractures that can be anatomically reconstructed, ie, transverse fractures, fractures with a large butterfly fragment, long oblique or spiral fractures, and intraarticular fractures. The potential disadvantages of open fracture reduction include iatrogenic contamination, additional soft-tissue damage, and impairment of blood supply. To minimize these problems, the surgical approach should follow the normal fascial planes and the incision should be of sufficient size to permit adequate exposure of all the fracture fragments. Halsted's principles of fracture fixation—preservation of all soft-tissue attachments to bone fragments, avoidance of excessive trauma, and careful handling of soft tissues, nerves, and vessels—will further minimize these problems.

Transverse fractures may be reduced by elevating the fractured bone ends out of the incision and bringing them into contact with each other. Pressure is slowly applied to replace the bones in a normal position. (**Fig | Anim 1-6**) Alternatively, a slim instrument, such as an osteotome or spay hook, may be used to lever the bone segments into alignment. (**Fig | Anim 1-7**) If fissure lines are present, the bone should be supported by cerclage wire before levering it into position. Eccentrically placed fractures such as transverse distal radial fractures may be better reduced and maintained in reduction by securing a contoured plate to the short distal segment and reducing the proximal segment to the plate. The reduction is maintained by securing the plate to the proximal segment with plate holding forceps. (**Fig | Anim 1-8**) Care must be taken to contour the plate appropriately, including torque where necessary, to achieve anatomical fracture reduction [46].

Long oblique fractures can be reduced by securing the bone segments with bone-holding forceps and distracting the segments as far as possible. Two self-retaining pointed reduction forceps may be positioned obliquely to the fracture line and used to slowly force distraction of the segments until anatomical reduction is achieved. The reduction is maintained with the pointed reduction forceps while lag screws or cerclage wires are applied [46] (**Fig | Anim 1-9**).

A variation of open reduction is the "open-but-do-not-touch" technique that permits viewing of the fracture fragments with minimal biological consequences. The major bone segments are manipulated but the fracture fragments are not disturbed. The bone is distracted to length with an intramedullary pin or nail, and the major segments are realigned by the tension on the surrounding tissues pulling them towards the central axis of the bony column. The surgery site is liberally lavaged, an autogenous cancellous bone graft applied and the wound closed. The same radiographic criteria used to evaluate successful closed reduction of fractures are used after this type of fixation.

Indirect reduction techniques are essential to the success of "biological" treatment of comminuted or nonreducible fractures. These techniques rely on aligning fragments by distracting the bone ends instead of manipulating the fracture site. Distraction may be achieved by traction and countertraction applied to the limb as used in the hanging limb technique (**Fig | Anim 1-10**). Traction is applied during patient clipping and skin preparation by suspending the

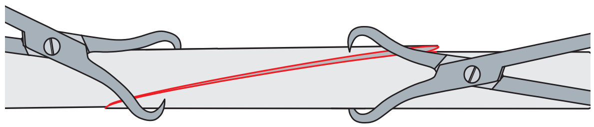


Fig | Anim 1-9

Animation

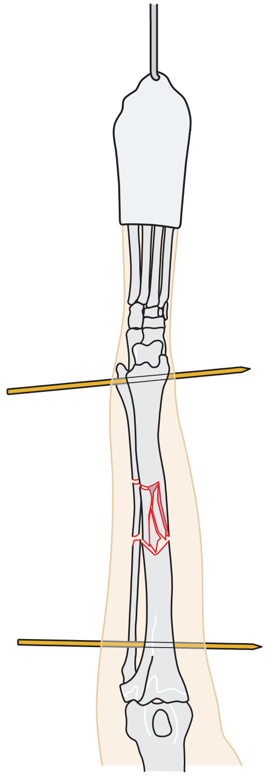


Fig | Anim 1-10

Animation

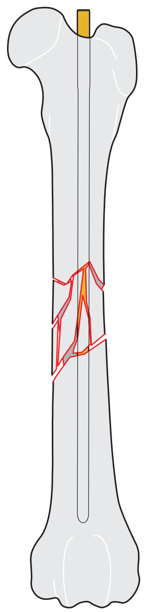


Fig | Anim 1-11

Animation

"Open-but-do-not-touch" is an indirect reduction technique combined with an open approach. The fracture fragments may be visualized, but are not directly manipulated.

Indirect reduction is the alignment of fracture fragments by distraction of the bone ends.

Review postoperative radiographs using the four **A**s mnemonic:
A = alignment
A = apposition
A = apparatus
A = activity

limb from a drip stand and using the animal's own weight to eventually fatigue the muscles. Alternatively, an intramedullary pin may be used to push the distal segment away from the proximal segment (**Fig | Anim 1-11**) prior to stabilizing the fracture with an external fixator (as in a "tie-in configuration") or buttress plate (as in a plate-rod construct). Regardless of technique, as the bone ends are distracted, the tension on the surrounding soft tissues guides the fragments into alignment [47].

Local and regional anesthetics and analgesics (ie, epidural analgesia, peripheral nerve blocks, surgery site infiltration, brachial plexus blocks, and intraarticular blocks) also facilitate most appendicular and pelvic fracture reduction and repair as they decrease the intraoperative pain response and provide good muscle relaxation [19, 20].

9 Postoperative management

Postoperatively, all fractures should be evaluated radiographically for alignment, reduction, and implant placement. The four **A**s mnemonic devised by Drs Egger and Schwarz is useful for ensuring a systematic evaluation of postoperative radiographs [46].

Alignment

Alignment of the fracture fragments into their normal orientation is essential to prevent angular and torsional displacement of the joint above and below the fracture. Orthogonal view radiographs should be inspected to ensure normal limb alignment.

Apposition

A certain amount of cortical apposition of the fracture fragments is necessary to ensure timely bone healing. As a role of thumb, 50% cortical apposition is necessary to prevent delayed union when the repair is viewed in both the craniocaudal and lateral projections. However, the amount of acceptable cortical apposition will vary depending upon the type of fracture fixation selected. For example, cortical apposition should be near perfect in an anatomically reconstructed fracture whereas with biological methods of fracture fixation, such as the external fixator or a plate-rod configuration, one would forgo reconstruction of the fracture fragments to preserve their blood supply.

Apparatus

Critical evaluation of implant selection and application on postoperative radiographs can often predict problems such as implant failure, especially in a situation where the rules of implant application are not strictly followed. Pertinent questions one should ask are:

- Was a suitable implant selected and appropriately applied in the repair?
- Were the rules of implant application followed?
- Is the implant properly positioned?

In addition, radiographs should be serially checked for evidence of implant loosening or premature failure until bone healing is radiographically complete.

Activity

Activity mainly refers to the biological activity of the bone in response to the fixation used (ie, is the fracture healing?). Most fractures heal within 12–16 weeks, but time to bone union is dependent upon several factors (such as age of the animal, degree of trauma, presence of infection, and method of fixation). Fractures should be radiographed every 6–8 weeks to evaluate bone healing and implant position. Activity may also be used to assess postoperative return to function after fracture repair. A significant delay in return to function or a sudden onset of lameness may indicate implant loosing or failure, infection, or issues with malalignment, degenerative joint disease, or neurological impairment.

Postoperatively, most patients with fractures distal to the elbow and stifle are placed in a soft-padded or modified Robert Jones bandage for 12–24 hours after fracture repair.

A well applied bandage reduces postoperative swelling, pain, and contamination, supports the limb and improves patient comfort. Repaired fractures of the humerus, femur, or axial skeleton are not usually bandaged. However distal extremity fracture repairs below the carpus and tarsus may require a Robert Jones bandage to limit swelling. Casts and splints are rarely needed if the repair is stable and appropriately applied. However, where adaptation osteosynthesis has been employed, external coaptation is required to support relatively weak implants.

Written discharge instructions should describe wound care, suture removal, exercise regimen, and bandage, cast, or splint management. This will encourage good client cooperation and reduce the possibility of potentially disastrous misunderstandings.

A soft-padded bandage applied postoperatively will reduce swelling and increase patient comfort.

Apply local hypothermia in multiple short sessions (5–15 minutes up to four times daily) to prevent reflex vasodilation and edema during the first 72 hours after surgery.

Local hyperthermia is applied during the later stages of recovery (> 72 hours postsurgery) when it can be combined with other forms of physical therapy (massage or exercise).

Canine rehabilitation is the veterinary equivalent of the human oriented profession of physical therapy. It incorporates physical or mechanical agents such as light, heat, cold, water, electricity, massage and exercise in the treatment of orthopedic and neurological disease.

Historically, rehabilitation has not played an important role in the management of a trauma patient in veterinary medicine [48]. Standard postoperative care has essentially involved support and confinement of the fracture patient until bone union. In recent years, however, veterinarians have adopted therapy techniques and modalities from the human field of physical therapy. **When properly administered, physical therapy prevents musculoskeletal disability, decreases healing time, and facilitates the restoration of normal function of damaged tissues** [49]. As a result, canine patients recover sooner and more completely from surgical and traumatic events.

There are six basic therapeutic modalities used to decrease pain, reduce inflammation, and stimulate normal healing responses: local hypo- and hyperthermia, massage, therapeutic exercise, hydrotherapy, ultrasound, and electrical stimulation.

Local hypothermia is used in the acute (< 72 hours) postinjury period to stimulate vasoconstriction, decrease nerve conduction velocity, and encourage skeletal muscle relaxation [50]. Vasoconstriction reduces arterial and capillary blood flow and therefore minimizes fluid leakage and edema. Analgesia is provided by alteration of sensory nerve conduction and reduced muscle spasm. Common forms of therapeutic cold include commercially available reusable ice and gel packs, continuously circulating cold-water blankets, homemade ice packs and towels, ice massage, and cold water hydrotherapy. Local hypothermia applied with compression has been shown to reduce skin temperatures by 27°C [51, 52]. The cooling effects of local hypothermia on deeper tissues are less profound and more unpredictable, depending upon the application method, the initial temperature of the treated area, and the duration of treatment [53]. Application of local hypothermia should be limited to multiple short sessions (5–15 minutes up to four times daily) to prevent reflex vasodilation and edema [50, 53–55].

Heat can be applied locally in the form of hot packs, towels, and water blankets. **Local hyperthermia** dilates capillaries, elevates capillary hydrostatic pressure, and increases capillary permeability and filtration. In addition to elevating skin temperature and causing a local histamine release, cellular metabolism is increased and muscle spasm is abolished [56]. However, local hyperthermia has a narrow therapeutic window (40–45°C) and is contraindicated in the neurological patient with reduced sensory input or the vascularly impaired patient [56]. Care must also be taken not to apply heat prematurely after a traumatic injury as it can induce vascular leakage and thus potentiate postoperative swelling [56]. Therefore, **local hyperthermia has few indications in the postoperative period and should be reserved for the later stages of recovery (> 72 hours postsurgery) when it can be combined with other forms of physical therapy (massage or exercise).**

Massage is the therapeutic manipulation of soft tissues and muscle by rubbing, kneading or tapping. Benefits of massage include increased local circulation, reduced muscle spasm, attenuation of edema, and breakdown of irregular scar tissue formation. The physiological properties of massage are due to both reflex and mechanical effects. Reflex effects are based on stimulation of peripheral receptors producing central effects of relaxation while peripherally producing muscular relaxation and arteriolar dilation. Mechanical effects include increased lymphatic and venous drainage thereby removing edema and metabolic waste. Increased arterial circulation enhances tissue oxygenation and wound healing, while manipulation of restrictive connective tissue enhances range of motion and limb mobility.

The most common techniques of massage used in veterinary medicine are effleurage, pétrissage, cross fiber massage, and tapotement. Effleurage is a form of superficial or light stroking massage and is generally used in the beginning of all massage sessions to relax and acclimatize the animal. Pétrissage is characterized by deep kneading and squeezing of muscle and surrounding soft tissues. Cross fiber massage is also a deep massage that is concentrated along lines of restrictive scar tissue and is designed to promote normal range of motion [55]. Tapotement involves the percussive manipulation of the soft tissues with a cupped hand or instrument and is often used to enhance postural drainage for respiratory conditions. Contraindications for massage are unstable or infected fractures, and the presence of malignancy. However, in most patients, massage is a valuable procedure, especially in a trauma patient with restricted mobility [56].

Therapeutic exercise is the performance of physical exertion to improve fitness and quality of life. It may be divided into two forms: passive and active. Passive range of motion (PROM) exercise involves the movement of the limbs and joints by the therapist with no effort being exerted by the animal. The goals of PROM are to maintain normal range of joint motion to prevent soft tissue and muscle contracture, and to minimize joint cartilage atrophy associated with prolonged immobilization and trauma [48]. Blood flow improves, as well as sensory awareness of the affected joints and limbs. However, PROM exercises do not prevent muscle atrophy, nor do they improve muscle strength or endurance. They assist blood circulation but not to the same degree as assisted or controlled active therapeutic exercise [48].

Controlled active therapeutic exercise is performed by the animal and can be assisted or resisted. These exercises help to build strength, muscle mass, agility, coordination, and cardiovascular health and can be used as a tool long after the patient is healed from its trauma/surgery to improve overall health [48]. The intensity of the activity is closely matched with the patient's recovery level. Controlled active therapeutic exercises include prolonged, momentary, and repeated sits, downs, stands, stays, stairs, walking inclines and hills, and weight-shifting exercises [48]. These activities are performed later during the recovery process and can be used indefinitely.

Hydrotherapy in combination with massage is an excellent method to remove lymphedema from extremities, while relaxing the patient and cleansing the limb. Cold-water hydrotherapy may be employed as soon as the surgical incision has a fibrin

Massage is the therapeutic manipulation of soft tissues and muscle by rubbing, kneading, or tapping.

Passive range of motion (PROM) exercise is performed by the therapist to maintain normal joint range of motion to prevent soft-tissue and muscle contracture, and to minimize joint cartilage atrophy associated with prolonged immobilization and trauma.

Therapeutic exercise is the controlled activity performed by the animal to build strength, muscle mass, agility, coordination, and cardiovascular health.

Therapeutic ultrasound is the delivery of acoustic vibrations to produce the deepest form of physiological heat and cellular inflammation. It is used to treat chronic scar tissue and adhesions.

Neuromuscular stimulation is the use of a pulse generator and electrodes placed over selected weakened or paralyzed muscle groups to create an artificial contraction. It may be indicated following fracture treatment that necessitates prolonged joint immobility or fractures with neurological impairment.

Recovery in most patients is improved with simple fundamental techniques such as massage, cold packing, PROM, and controlled exercise regimens that involve mostly the investment of time on the surgeon's part.

seal—generally within 24 hours surgery. This form of hydrotherapy requires little equipment other than a bath and a hose. Increasing the water depth and the temperature to 30°C, whirlpools, swimming pools, and underwater treadmill systems all provide a nongravitational environment in which it is ideal to perform nonconcussive active-assisted exercise. The natural properties of water provide both buoyancy and resistance and improve limb mobility and joint range of motion. However, caution should always be used with any water exercise as some dogs dislike water or resist swimming, and may become frantic unless they are acclimatized to the regimen [48]. At no time should an animal be left unattended during a hydrotherapy regimen, as drowning is a real risk.

Therapeutic ultrasound is based upon the delivery of acoustic vibrations to produce the deepest form of physiological heat and cellular inflammation. The physiologic effects of ultrasound may be divided into two categories: thermal and nonthermal. The thermal effects of ultrasound increase connective tissue extensibility and vascularity, and provide a form of temporary nerve blockage, thus promoting muscular relaxation and pain relief. Nonthermal effects of ultrasound include the acceleration and compression of the inflammatory phase of healing, an increase in the local circulation, and a decrease in edema. There is also a mechanical release of endorphins, encephalins, and serotonin for pain control, and a stimulation of collagen synthesis and bone growth [57]. The indications for ultrasound are somewhat limited in the immediate postoperative phase of fracture treatment but may be of more use in the treatment of chronic scar tissue and adhesions.

Neuromuscular stimulation is indicated in fracture treatment that necessitates prolonged joint immobility or fractures with neurological impairment. Neuromuscular stimulation prevents disuse atrophy and improves limb performance by recruiting contracting fibers and increasing maximum contractible force of affected muscles. The electrical stimulation device consists of a pulse generator and electrodes, which are placed over selected weakened or paralyzed muscle groups to create an artificial contraction. Pulse amplitude, rate and cycle length may be varied to suit the comfort of the patient. Reduction of muscular pain and edema due to improved blood flow also occurs. Combining neuromuscular stimulation with PROM exercises improves range of joint motion. It also prevents muscle contracture and is particularly indicated in fractures of the distal femur of the young dog.

Rehabilitation should be started as soon as the fracture is stabilized. In the case of major fractures, early massage and PROM exercises can be used to reduce edema and muscle spasm to assist pain relief and improve circulation [54]. The number of treatments per day and the total number of treatments is dependent on the severity of the fracture and the response of the animal [54]. The nature of the treatment is influenced by factors such as facilities, equipment, and trained personnel [54]. However, it is a fallacy to assume that one needs advanced training and equipment to perform physical therapy in animals. Most patients will experience improved recovery with simple fundamental techniques such as massage, cold packing, PROM, and controlled exercise regimens that involve mostly the investment of time on the surgeon's part.

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2.1 Screws and plates

Author Daniel Koch

2.1 Screws and plates

1 Introduction

In the early 1960s, interfragmentary compression techniques, leading to direct bone healing, were the gold standard for treating long bone fractures in small animals. Absolute stability was achieved by the application of compression devices such as lag screws and compression plates. However, this conventional method of treating fractures requires an extensive surgical approach and demands skill and expertise to minimize biological complications such as iatrogenic soft-tissue damage, early bone necrosis underneath the plate and late stress protection of the bone.

Recent developments have led to the principle of biological fracture healing in long bone fractures. This is characterized by minimal biological damage during the repair together with flexible fixation. Minimal damage is achieved by eliminating anatomical reduction, by practicing indirect reduction techniques and by concentrating on axial alignment of the fragments. Less surgical trauma is therefore created. Flexible fixation is achieved by wide bridging of the fracture zone using locked nails, bridge plating, or internal or external fixators. It leads to indirect bone healing with callus formation. Healing will occur under optimal biological conditions rather than absolute stability [1].

The issue of implant–bone contact has been addressed in a number of ways. Limited contact devices such as the LC-DCP (limited contact dynamic compression plate) reduce the plate–bone contact without loss of friction between the implant and bone to transmit forces. This friction is further avoided by the locked-screw technique (LCP, UniLock), which in turn reduces bone necrosis.

2 Instrumentation

Instruments are required to facilitate the surgical approach to a fracture, to assist fracture reduction, and to create osteosynthesis.

2.1 Instruments to assist the surgical approach

Special instruments for the surgical approach include retractors, levers, and elevators. Self-retaining retractors or soft-tissue retractors with smooth or pointed ends can be carefully placed underneath musculature or into joint capsules. Gelpi retractors are particularly useful and may be used in a wide variety of situations. Bone levers, such as Hohmann retractors, may be used for retracting muscles by placing their tips under a solid structure and depressing the muscle under their arm. Periosteal elevators may be carefully used to separate soft tissues from bone to reveal the major bone fragments.

2.2 Instruments for reduction

Reduction reverses the process that created the fracture. It calls for forces and moments opposite to those that resulted in the fracture. These methods may be operative or nonoperative, open or closed. Meticulous preservation of blood supply has to be weighed against perfect fracture reduction. Indirect methods have the advantage that the fracture area remains covered by surrounding soft tissue, but they are technically demanding. Direct reduction implies that the fracture is exposed surgically. The fragments are grasped by instruments and apposed by applying forces close to the fracture zone. In simple diaphyseal fracture patterns, direct reduction is technically straightforward and the result is easy to control. **In more complex fractures, the repeated use of bone clamps and other**

reduction tools or implants may devitalize the fragments, with disastrous consequences for the healing process [2].

The standard pointed reduction forceps is an instrument well suited for direct fracture reduction since the points minimize damage to the periosteum. In some oblique midshaft fractures, one reduction forceps may be sufficient to maintain fracture reduction (**DVD | Video 2.1-1**). In most cases, however, two are required for the manual distraction of the main fragments, followed by proper axial alignment and controlled reduction (**DVD | Video 2.1-2**). In cortical bone, the small-tipped Hohmann retractor can be used as a lever to achieve reduction (**DVD | Video 2.1-3**). An intramedullary nail may temporarily be used as a reduction device, along which the fragments are aligned. In bones that are difficult to approach (eg, the pelvis), pins may be placed away from the fracture site in order to manipulate the fragments (**DVD | Video 2.1-4**). Temporary cerclage wire may also be used, but care must be taken not to denude bone during its application (**DVD | Video 2.1-5**). Special reduction clamps have been developed for acetabular fractures (**DVD | Video 2.1-6**).

Video

Video

Video

Video

Video

Video

2.3 Instruments for osteosynthesis

Instruments are designed for the proper application of implants. Plate osteosynthesis is performed using the following standard instrumentation: drill machine with coupling devices for the drill bit and for K-wires, suitable sized drill bits and taps, sleeves for drill bits and taps, depth gauge, double drill guide for screws, plate-holding forceps, bending irons, aluminum template, and screw driver. The equipment differs according to the size of the implant and the type of plate fixation. If an oscillating mode of drilling is desired, drills with three flutes are chosen rather than the more conventional two.

3 Screws

A screw is a very efficient implant for repairing a fracture using interfragmentary compression, or for fixing a splinting device such as a plate, nail, or fixator to a bone. Screw purchase in the bone depends on the implant–bone interface. The goal is to achieve as much contact area as possible in a sufficiently stable implant of minimal size. In veterinary practice, the cortex and the cancellous bone screws are generally used. **Cancellous bone screws have a larger outer diameter, a deeper thread, and a larger pitch than cortex screws and are used in metaphyseal or epiphyseal bone. The cortex screw is designed for the diaphysis.** Newly developed screws for use in man, such as self-tapping screws, monocortical screws and those used in locking systems, are likely to find an increasing application in animals, since patient morbidity can be decreased (**Fig 2.1-1**).

3.1 Cortex screw

Since the strength of the bone reduces as the size of the screw increases, it is recommended that the screw diameter should not exceed 40% of the diameter of the bone. Accordingly there are a number of different sizes of cortex screws available to enable fixation of bones of different diameters. The normally available screws are the 5.5, 4.5, 3.5, 2.7, 2.0, and the 1.5 mm cortex screws, all in different lengths (**Fig 2.1-2**). The frequently used 3.5 mm cortex screw has a 6 mm head with a 3.5 mm hexagonal recess, which corresponds to the screwdriver. The outer diameter of the screws shaft is 3.5 mm; the core diameter is 2.4 mm.

Self-tapping screws are designed in such a way that once a pilot hole has been drilled into bone, they

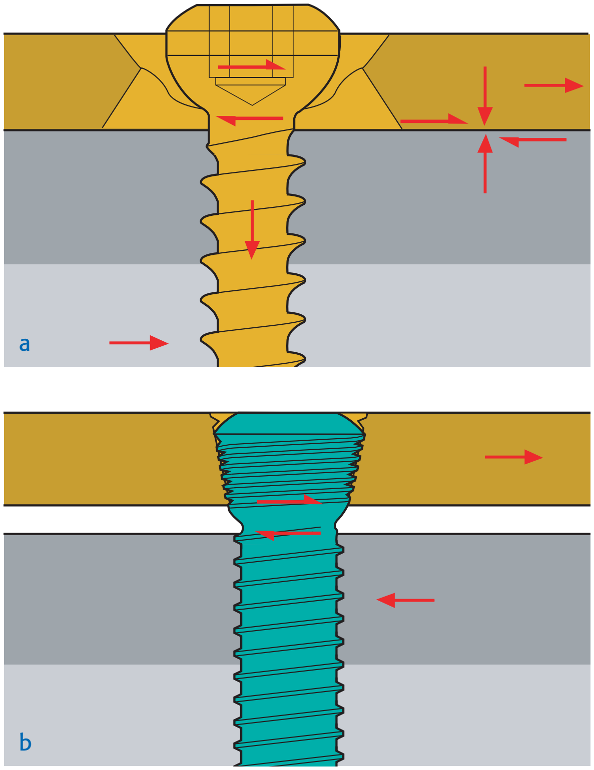


Fig 2.1-1a–b

a Typical force distribution of a plate osteosynthesis without angular stability: The screw tightening moment leads to surface pressure between the plate and bone. The friction thus created in the plate–bone contact zone stabilizes the bone fragment in relation to the load carrier. This system only becomes statically secure after bicortical screw fixation.

b Typical distribution of forces for a locking internal fixator (LIF) osteosynthesis with angular stability: This configuration is statically secure with only monocortical fixation since the so-called locking head screw (LHS) is anchored in a mechanically stable manner in the load carrier, perpendicular to the "plate" body. Such systems act more like fixators than plates.

can be inserted by simply screwing them in. The pilot hole is somewhat larger than the core of the screw. Resistance to screw insertion may compromise its accuracy, particularly if the screw is being inserted obliquely to lag two fragments together. Self-tapping screws can be removed and reinserted without weakening their hold in bone. However, if inadvertently misdirected, they will cut a new path and destroy the thread that has already been cut. Self-tapping screws should therefore not be used as lag screws.

Cortex screws are designed for use in diaphyseal bone.

Self-tapping screws are best used in applications where applied only once.

Self-tapping screws should not be used as lag screws.

The nonself-tapping screw requires a predrilled pilot hole. During drilling, a sharp drill bit and meticulous cooling with sterile physiological saline will reduce thermal necrosis of the bone. The bone is then cut with a tap, which exactly corresponds to the profile of the screw thread. Because the thread is cut with a tap, the pilot hole corresponds in size almost to the core of the screw and the screw thread has a much deeper bite into the adjacent bone. Much less heat is generated when the screw is inserted because there is less resistance. The tap is designed in such a way that not only is it much sharper than the thread of a screw, but it also has a more efficient mechanism to clear the bone debris. Therefore debris does not accumulate to clog the screw threads and obstruct screw insertion. Screws can be removed and reinserted with ease, and without fear of inadvertently cutting a new channel, as the screw alone is incapable of cutting a thread in cortical bone.

Standard screws are best used when there is an anticipated need to replace or reposition the screw.

3.2 Cancellous bone screw

Cancellous bone screws have a relatively thin core and wide and deep threads. The increase in the ratio of the outer diameter to the core gives this type of screw considerably increased holding power in the fine trabecular bone of the metaphyses and epiphyses.

Screws, drill bits, and taps

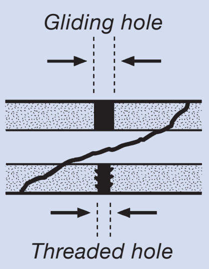
Screws											
Screw diameter (mm)	1.5	2.0	2.7	3.5	4.0		4.5	5.5		6.5	
Screw type		**Cortex** self-tapping		**Cortex**	**Cancellous** nonself-tapping		**Cortex**			**Cancellous** nonself-tapping	
	and nonself-tapping	and nonself-tapping	and nonself-tapping	self-tapping and nonself-tapping	partially threaded	fully threaded	self-tapping and non-self-tapping	nonself-tapping	16 mm threaded	32 mm threaded	fully threaded
Drill bits and taps											
Drill (mm) for gliding hole	1.5	2.0	2.7	3.5	–		4.5	5.5		4.5 in hard bone	
											
Drill bit (mm) for threaded hole	1.1	1.5	2.0	2.5	2.5		3.2	4.0		3.2	
Tap (mm) (in hard bone and for nonself-tapping screws	1.5	2.0	2.7	3.5	4.0		4.5	5.5		6.5	

Fig 2.1-2 Summary of available standard screws and their corresponding drill bits and taps.

Cancellous bone screws are either fully or partially threaded. The fully threaded screws are used for fastening devices such as plates to metaphyseal and epiphyseal bone. The partially threaded screws are used as lag screws. In this instance, tapping is only necessary in the near cortex. The screw can easily cut a thread for itself in the cancellous bone, and its holding power is increased if the thread is not cut.

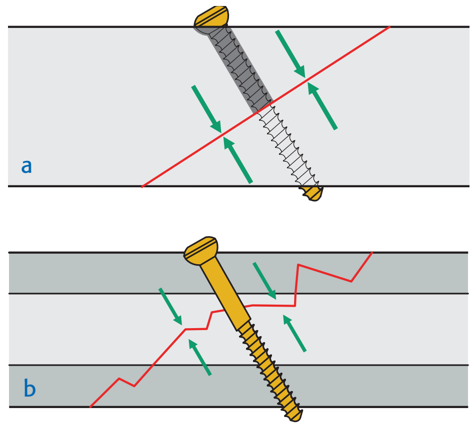
3.3 Shaft screw

The shaft screw is a cortex screw with short threads and a shaft, the diameter of which is equal to that of the thread (Fig 2.1-3). **The shaft screw is used as a lag screw in diaphyseal bone.** When an inclined screw is used, so that its head rests on a surface parallel to the long axis of the bone, the shaft screw should be selected. This avoids its head engaging in the gliding hole, thereby losing a degree of compression.

3.4 Cannulated screw

Cannulated bone screws have a central hollow core and are inserted over K-wires that act as guides. Both 3.5, and 6.5 mm cancellous screws are available in the cannulated version. **Cannulated bone screws are employed as lag screws and are particularly suited for the reconstruction of metaphyseal or epiphyseal fractures such as those occuring in the distal humerus or proximal femur.**

Fig 2.1-3a–b Lag screw effect using fully and partially threaded screws.



a By overdrilling the bone thread in the near fragment to the size of the outer diameter of the screw thread, the threaded part of the bone screw may glide in relation to the bone. When this technique is used with an angled screw whose head impacts on one side only, one component of the axial screw force acts along the long axis of the bone which tends to shift the screw head toward the fracture. The screw thread within the gliding hole may then engage and compression is lost for a varying degree.

b Compression can also be achieved with a shaft screw whose shaft does not produce axial load.

Cannulated bone screws are designed for use in metaphyseal or epiphyseal bone.

The term lag screw refers to the function of the screw. Both fully threaded and partially threaded screws can be used as lag screws.

The fully threaded cortex lag screw is applied with a smaller pilot or threaded hole in the far cortex and a larger clearance or gliding hole within the near cortex.

Lag screws are used mainly to provide interfragmentary compression between two bone fragments.

Video

3.5 Locking head screw

Locking head screws, as their name implies, have heads that lock in the plate hole (**Fig 2.1-1b**). They are used in internal fixators such as the locking compression plate (LCP) and UniLock system, and they may be self-drilling, self-cutting, and used as monocortical screw. Locking head screws provide better anchorage as their position in relation to the plate is fixed. They can also function as a fixed angle device, which is an advantage in metaphyseal fractures and when minimally invasive techniques are used.

3.6 Application

3.6.1 Lag screw

A fully threaded screw can be used as a lag screw, provided the thread is prevented from engaging within the cortex next to the screw head (cis or near cortex). This is done by drilling a clearance or gliding hole of a diameter equal to, or slightly larger than, the outer diameter of the screw thread in the near cortex. A hole in the trans or far cortex is drilled, corresponding to the core diameter of the screw, the entire drill hole length is measured and the drill hole in the far cortex is tapped. Thus, the fully threaded cortex lag screw is applied with a smaller pilot or threaded hole in the far cortex and a larger clearance or gliding hole within the near cortex (**Fig | Anim 2.1-4, Fig | Video 2.1-5**). A partially threaded screw can be used as a lag screw provided the threaded portion of the screw only engages the far cortex (**DVD | Video 2.1-7**).

In order to achieve maximal interfragmentary compression, the lag screw must be inserted in the middle of the fragment equidistant from the fracture edges and directed at a right angle to the fracture plane.

In order to increase contact between the bone and screw head, the near cortex is reamed with a countersink. The depth of the drill hole is measured after countersinking but before tapping. In areas where cancellous bone is covered by a thin cortical layer, forces may be distributed by using a washer under the screw head.

When an inclined screw thread produces axial force, one component of the force tends to shift the screw head along the bone surface toward the fracture (**Fig | Video 2.1-6**). Under such conditions the use of a lag screw with a shaft corresponding to the outer diameter of the thread (the so-called shaft screw) may be advisable. Otherwise, the screw thread may engage within the gliding hole and some efficiency may be lost (**Fig | Anim 2.1-7**).

3.6.2 Position screw

When the insertion of a lag screw will cause a fragment to collapse into the medullary cavity, it is preferable to use a position screw. The fragments are carefully held in position with pointed reduction forceps and a screw with position function is inserted. In this instance, thread holes are drilled in the cortex of both the far and near fragments. The drill hole is measured and tapped. When the appropriate screw is inserted, the position of the two fragments is maintained (**Fig 2.1-8, Fig | Video 2.1-9**).

3.6.3 Plate screw

Plate screws, as their name implies, are used to attach plates to bones. **The diameter of the screw is dictated by the size of the plate** (see 2.1 Screws and plates; 4 Plates; 4.1 DCP).

Fig | Anim 2.1-4a–f Technique for lag screw fixation after fragment reduction.

a The gliding hole is drilled the same diameter as the screw thread.

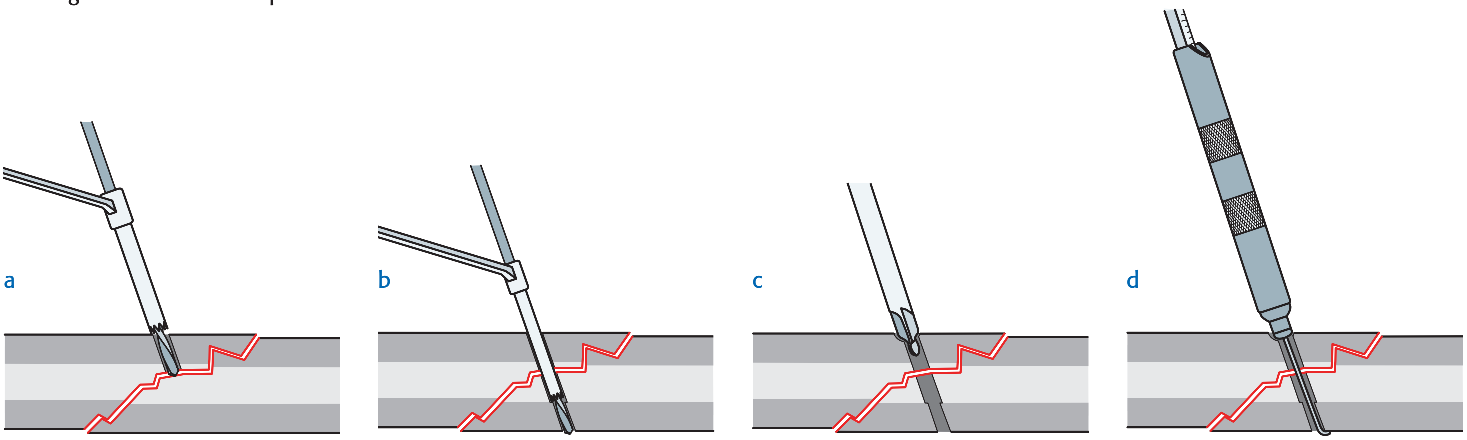
b The drill sleeve with outer diameter of the gliding hole and inner diameter of the thread hole is inserted. The hole is drilled in the far segment the same diameter as the screw core.

c The hole is countersunk to enlarge the contact area.

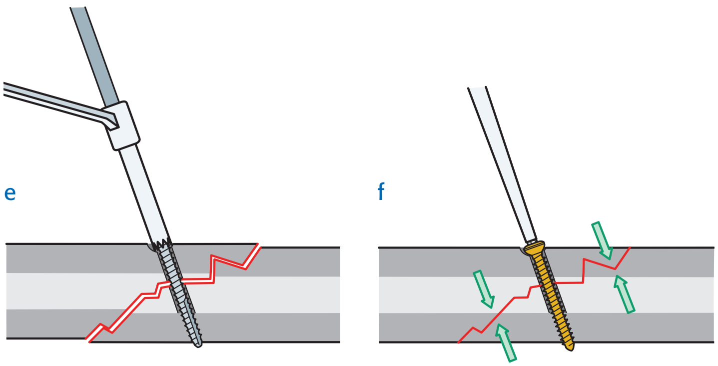
d The screw length is carefully measured.

e The thread hole is tapped.

f The appropriate screw is inserted and tightened. In order to achieve maximal compression, the lag screw must be inserted through the center of both fragments and must be directed at a right angle to the fracture plane.



Animation



Video

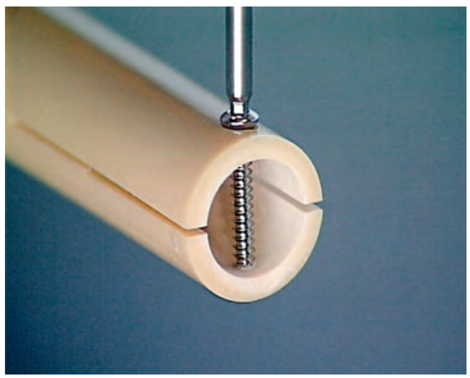


Fig | Video 2.1-5 Principle of lag screw insertion.

Video

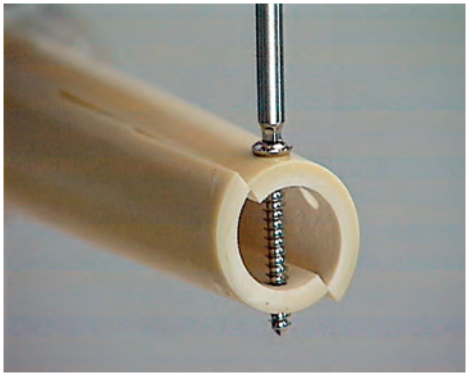


Fig | Video 2.1-6 Shear forces displace fracture fragments if a lag screw is not placed perpendicular to the fracture line.

Animation

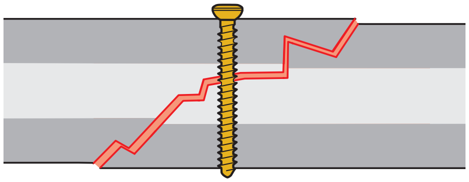


Fig | Anim 2.1-7 Failure to overdrill the near cortex prevents the screw from compressing the fracture. When both cortices are drilled and tapped, the screw functions as a position screw.

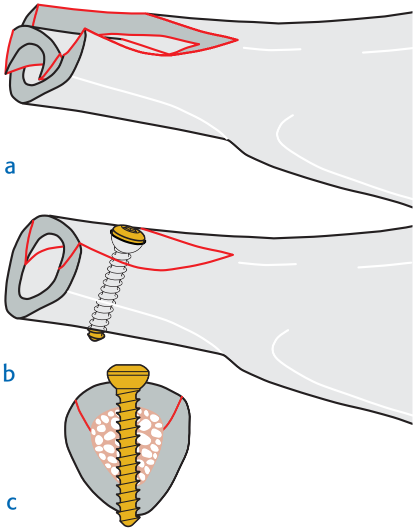


Fig 2.1-8a–c
Steps for inserting a position screw.

- a The fragments are reduced and maintained in position.
- b Both fragments are drilled with thread holes, measured, and tapped.
- c The inserted screw will not collapse the fragment.

Video

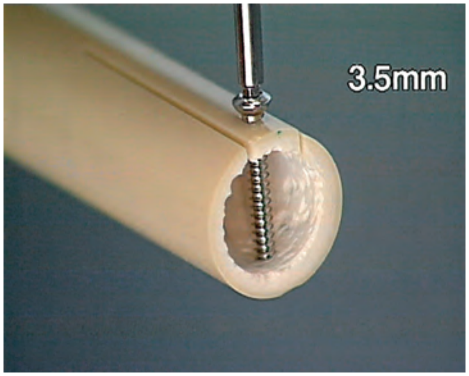


Fig | Video 2.1-9
Principle of position screw insertion.

In the case of a 3.5 mm screw used with a dynamic compression plate (DCP) 3.5 or limited contact dynamic compression plate (LC-DCP), the following steps are undertaken. First, the desired function of the plate must be determined (neutralization, compression, bridging, or buttress). The screw hole is drilled with a drill bit through the corresponding drill sleeve. A standard drill sleeve is used for the DCP and the universal sleeve for the LC-DCP (see 2.1 Screws and plates; 4 Plates; 4.2 LC-DCP). In both cases, the screw hole is slightly larger (2.5 mm) than the core of the screw (2.4 mm). The length is measured with the depth gauge. **If the correct screw length is not available, the next longer screw is chosen.** The hole is tapped (3.5 mm) and the screw is inserted with the screwdriver (**Fig 2.1-10**).

As a rule of thumb, the greatest forces that can be applied to the screwdriver when tightening a plate screw are as follows: two fingers for a 2.0 mm screw, three fingers for a 2.7 mm screw and the whole hand for a 3.5 mm screw. For more accurate tightening, torque limiting screw drivers are available. **To ensure axial alignment of the plate to the bone, plate screws are first applied at each end of the plate, then close to the fracture and finally, the remaining plate holes are filled.** Alternatively, if axial alignment is straightforward, the screws may be first applied next to the fracture and the holes filled on alternate sides of the fracture moving toward each end of the plate. In either case, the screws are retightened after they have all been placed until they are seated firmly.

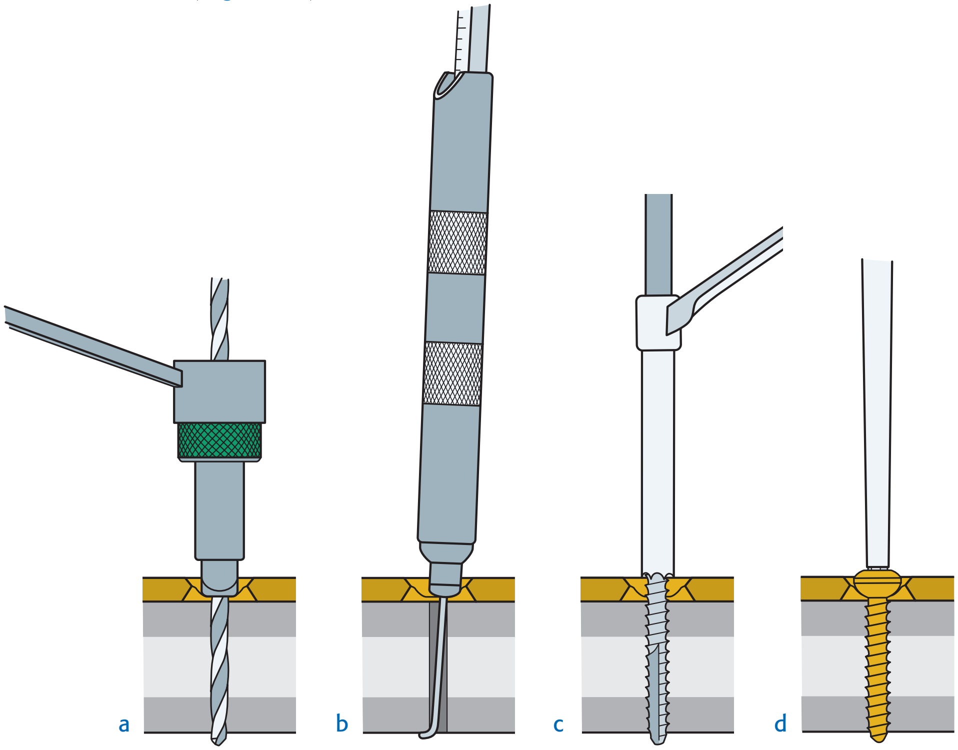


Fig 2.1-10a–d Application of a plate screw.
a Drilling of the hole in neutral position.
b Measuring the hole length.
c Tapping.
d Insertion of the screw.