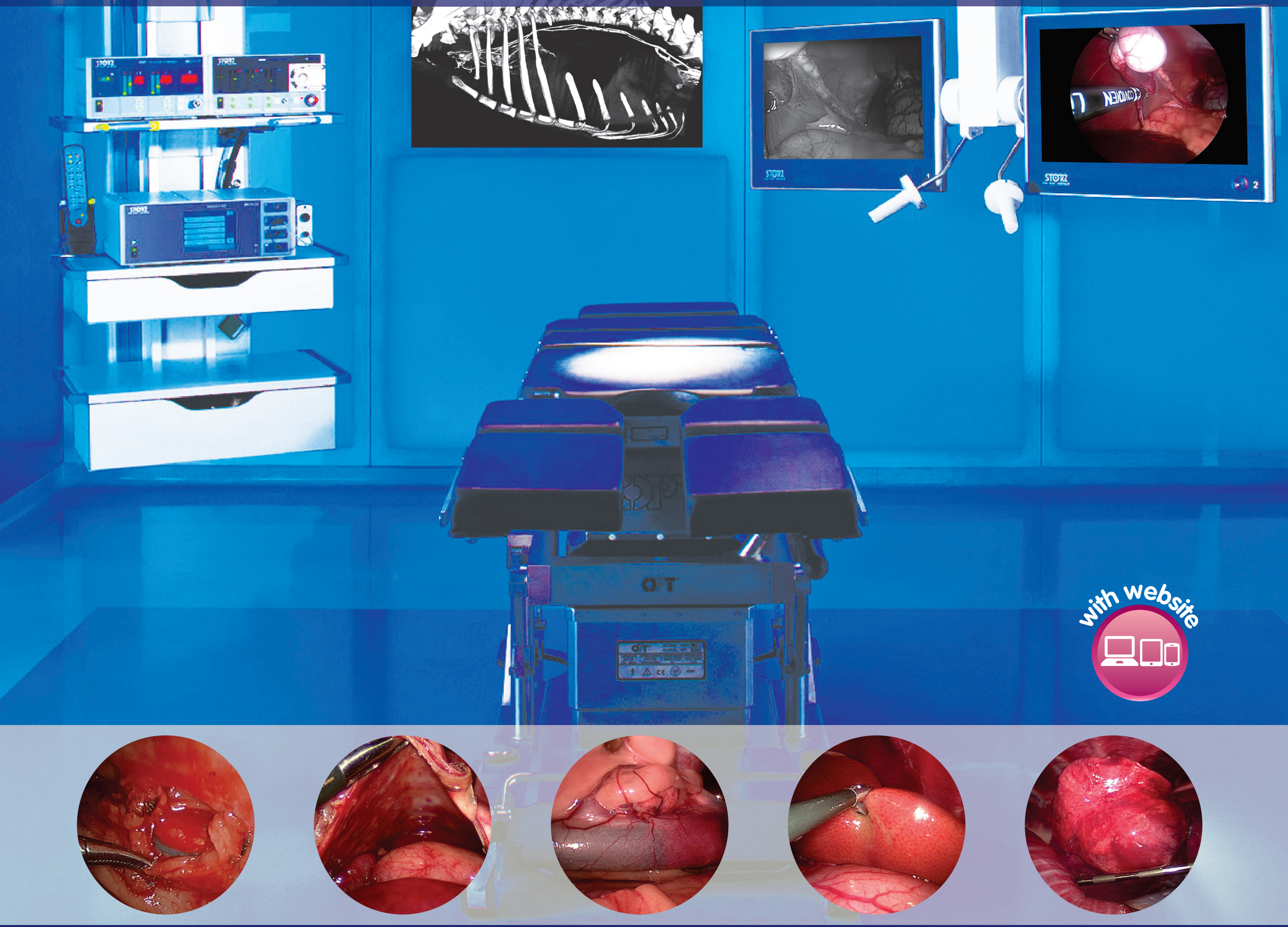
ADVANCES IN VETERINARY SURGERY

Small Animal Laparoscopy and Thoracoscopy

BOEL A. FRANSSON | PHILIPP D. MAYHEW



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Small Animal Laparoscopy and Thoracoscopy

To my husband Claude for inspiration and support in every aspect of life. To my daughters Selma and Ella for providing endless joy, life balance, and perspective. To the surgical residents who make me grow as a mentor and a surgeon. And to my parents, Sivert and Anita, whose unconditional love and support formed my foundation.

— BAF

To my parents Alan and Hildegard for their unwavering support, kindness, and generosity. To my wife Kelli and my children Reece, Aidan, and Brynn for making life so rich and rewarding and full of joy and laughter.

— PDM

Small Animal Laparoscopy and Thoracoscopy

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Foreword

The American College of Veterinary Surgeons (ACVS) Foundation is excited to present *Small Animal Laparoscopy and Thoracoscopy* in the book series titled *Advances in Veterinary Surgery*. The ACVS Foundation is an independently charted philanthropic organization devoted to advancing the charitable, educational, and scientific goals of the ACVS. Founded in 1965, the ACVS sets the standards for the specialty of veterinary surgery. The ACVS, which is approved by the American Veterinary Medical Association, administers the board certification process for Diplomates in veterinary surgery and advances veterinary surgery and education. One of the principal goals of the ACVS Foundation is to foster the advancement of the art and science of veterinary surgery. The Foundation achieves these goals by supporting investigations in the diagnosis and treatment of surgical diseases; increasing educational opportunities for surgeons, surgical residents, and veterinary practitioners; improving surgical training of residents and veterinary students; and bettering animal patients' care, treatment, and welfare. This collaboration with Wiley-Blackwell will benefit all who are interested in veterinary surgery by presenting the latest evidence-based information on a particular surgical topic.

Small Animal Laparoscopy and Thoracoscopy is edited by Drs. Boel Fransson and Philipp Mayhew, both of whom are Diplomates of the ACVS. They have assembled the leaders in this field presenting sections on technical skills, equipment, fundamental techniques, and suggested procedures where these modalities can best be used. The ACVS Foundation is proud to partner with Wiley-Blackwell in this important series and is honored to present this book in the series.

Mark D. Markel
Chair, Board of Trustees
ACVS Foundation

Foreword

Minimal access surgery has revolutionized surgical care by providing precise, effective, and durable surgical interventions with minimal injury from access to body cavities. These techniques have expanded from the abdominal cavity and pelvis to the retroperitoneum, thoracic cavity, and joint spaces. The impact of this novel approach has been enormous, whether applied in the urban area, rural environments, or the developing world. Extensive published data confirm the recovery benefits and the reduction in complications associated with these novel surgical approaches.

The challenge in minimal access surgery has been to train surgeons to overcome the technical demands of these techniques. These involve primarily working with a monocular optical system while doing surgery in three dimensions, using long instruments constrained by trocars working across a fulcrum, decreased tactile feedback, and reduced range of motion. Suturing and knot tying, fundamental to most surgical procedures, can be especially difficult for new laparoscopists. However, these skills can be readily learned and applied clinically.

The response to these technical challenges has led to a new and better approach to surgical education using simulation-based principles. Programs such as the Fundamentals of Laparoscopic Surgery™ have been proven to be highly effective, efficient, and durable to train surgeons and to verify their technical skills before they apply these approaches to patient care.

These same advantages have been clearly demonstrated in veterinary surgery. *Small Animal Laparoscopy and Thoracoscopy,* by Drs. Boel Fransson and Philipp Mayhew, should be required reading for veterinary surgeons and veterinary surgical students who practice or plan to practice minimally invasive surgical techniques. This textbook provides an eloquent, well-illustrated, and up-to-date description of the applications of minimal access surgery in veterinary medicine, including specific recommendations for perioperative care. Furthermore, the authors address the educational opportunities for veterinary surgeons wishing to acquire the minimally invasive surgical skills required to perform these innovative procedures. *Small Animal Laparoscopy and Thoracoscopy* is a beautifully written and valuable resource for veterinary surgeons.

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Preface

Minimally invasive surgery (MIS) started in veterinary medicine around 20 years ago as a diagnostic tool, and now more than 100 publications already exist about different surgical techniques available to small animal surgeons. This book is the witness of the exponential development of MIS in veterinary practice over the past 5 years. All of the techniques described and illustrated in this textbook are currently used in veterinary practice. This book, edited by Drs. Boel Fransson and Philipp Mayhew, is the first textbook exclusively dedicated to veterinary MIS. The two editors recruited the most experienced authors in their own field to write different chapters. Each chapter is well illustrated to represent a solid base for general practitioners, surgeons in training, and board-certified surgeons.

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Approximately 25 years ago, a paradigm shift to minimally invasive surgical techniques occurred with the introduction of laparoscopy and thoracoscopy in human medicine. Although the world of veterinary surgery has taken somewhat longer to follow suit, it is now changing at a rapid pace driven in part by the introduction of new technology and the abundant opportunities for further training in advanced procedures. The previous textbook entirely dedicated to small animal laparoscopy and thoracoscopy was published a decade and a half ago. Since then, more than 200 articles have been published in peer-reviewed journals, and minimally invasive surgery has moved from being mainly a diagnostic tool in specialty practice into therapeutic applications in general and specialty veterinary practice.

This book is the first one entirely dedicated to laparoscopy and thoracoscopy, and it has brought together the most experienced surgeons from around the world in a joint mission to create an instructive review of minimally invasive surgical techniques. It is also the first book on the subject to be written by authors with significant experience of MIS in clinical populations of small animal patients. A strongly contributing factor to this community of veterinary surgeons has been the Veterinary Endoscopy Society (VES). Founded in 2003 by Dr. Eric Monnet, VES has brought veterinarians from around the world interested in endoscopic surgery together to share their ideas and experiences in the field of veterinary endoscopy. From this platform, a network of dedicated veterinarians formed, sharing a passion for surgical endoscopy. The editors are indebted to these experts and fine colleagues for their willingness to share their expertise and for their time and effort spent in the undertaking of this project. It is because of these authors we can share the most current information with the readership.

Although the editors believe that this book represents a certain "coming of age" for the field of veterinary laparoscopy and thoracoscopy, there is no doubt that this represents perhaps the end of the beginning. It is our hope that in the years to come the procedures described in the book will be performed more frequently. We also hope for that expansion to be paralleled with an appreciation for the value of critical scientific evaluation of results and outcomes. Although much data exists in the human literature to validate the benefits of many minimally invasive approaches we should not be complacent in the knowledge that if it is better in people, it must be better in our small animal patients. Ongoing and future studies performed using the principles of evidence-based medicine should form the bedrock of this subspecialty, and the results of these studies should guide our recommendations and indications for MIS in the future.

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We are indebted to the skilled work of our medical illustrator, John Doval, whose tireless hours of work were performed with relentless good humor and enthusiasm. He was responsible for creating all of the animations in the book as well as editing many of the figures. We also would like to extend a special word of gratitude to the companies that play a huge role in driving forward the development of MIS in veterinary medicine through innovation and education. In particular, Karl Storz Endoscopy and Covidien, Inc. have been ever present supporters of both the Veterinary Endoscopy Society and other hands-on educational offerings in the field.

In addition, we thank Erica Judisch, Wiley, for initiating the development of this book and for her expertise and support in the field of publishing. We also appreciate the assistance extended by her colleagues Nancy Turner and Catriona Cooper.

Finally, we want to express our gratitude to the ACVS Foundation who, in collaboration with Wiley-Blackwell, made production of this book possible.

BAF
PDM

About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/fransson/laparoscopy

The website includes:
- Videos (indicated by an "eye" icon in the margin)
- PowerPoint figures from the book

History of Small Animal Laparoscopy and Thoracoscopy

Boel A. Fransson

Veterinary minimally invasive surgery (MIS) as a surgical technique is unique because it had its origin in human application. Other biomedical techniques were traditionally developed in animal models and later applied to human patients. Therefore, the history of small animal MIS has to start with the overall history of laparoscopy. Parallel with the developments in laparoscopy were work in the chest cavity, but because much of the development were driven by urologists and gynecologists, the text below will often use the term laparoscopy interchangeably with *MIS*.

Endoscopy in the 19th Century

A variety of opinions exist on who should be credited with the invention of endoscopy. Some suggest to go back to Hippocrates (460–377 BC), who performed rectal examinations with a speculum.[7,8]

More consistently, the German physician Philipp Bozzini (1773–1809) has received credit for clinical use of his invention, the "Lichtleiter," the light conductor, a primitive endoscope for inspection of the ears, mouth, nasal cavity, urethra, rectum, bladder, and cervix. The Bozzini family was a well-to-do Italian family, but they had to leave Italy for Germany because of a lost duel by the father. Bozzini dedicated the last 5 years of his life, which was cut short by contracting typhus from his patients, to development of his instrument, a vase-shaped, leather-covered tin lantern using a wax candle light source (Figure 0-1).[3] Although the Austrian contemporary health authorities were satisfied with the instrument, a second opinion by the Vienna medical school, likely negatively influenced by the church, concluded that such an instrument should not be used.

In the latter part of the 19th century, interest was again renewed in using endoscopy. A French urologist, Antoine Jean Desormeaux (1815–1882), modified Bozzini's lichtleiter such that a mirror would reflect light from a kerosene lamp through a long metal channel, referring to his instrument as an "endoscope." Desormeaux is considered a leader in early endoscopy development and perhaps the first to successfully use the new technology for diagnostic and therapeutic use in clinical practice. Desormeaux's endoscope was certainly not without its flaws—the required positioning of the device entailed risks of burning the face of the physician or the thighs of the patient. Also, because catheter systems were not yet in use, urine would often "extinguish the flame, ruining the examination".[8]

The 1930s: The Glory Days

The 20th century saw rapid technology development, which led to more widespread promotion of endoscopy. Paralleled with this development were improvements in safety and operating procedures provided by antibiotics, better anesthesia, and blood

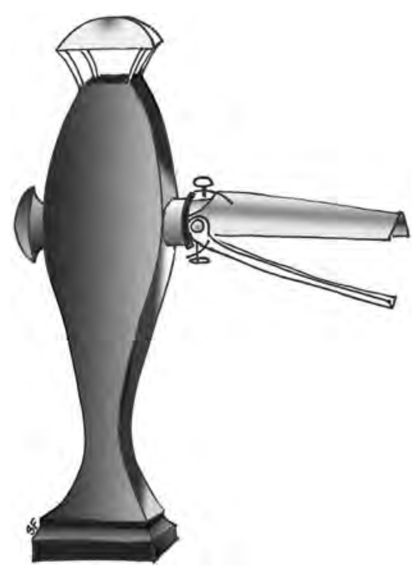

Figure 0-1 Bozzini's Lichtleiter, a vase-shaped, leather-covered tin lantern using a wax candle light source. (Courtesy of Dr. David C. Twedt.)

transfusions. By the 1930s, endo-urologists had embraced endoscopic technology with giddy enthusiasm, but surgical application was still lagging behind. Inadequate optics has been stated as one of the major reasons for this stall in progress.

Enter the German gastroenterologist Heinz Kalk (1895–1973), who in 1929 introduced a foreoblique lens system, which effectively increased the field of vision. Kalk is considered by many to be one of the greatest clinical laparoscopists of all time. He was disturbed by the contemporary high fatality rates associated with liver biopsies, and he was the first to introduce a safe and accurate method of endoscopic biopsies of the liver, gallbladder, and kidney. With Kalk's improvements, the increased usefulness of the endoscope invigorated surgeons to start using the technology. Before Kalk, endoscopy had mainly been applied by gynecologists and urologists. Kalk was fortunate to, just barely, make it out alive during the Stalingrad invasion of 1943. His survival was fortuitous for the development of laparoscopy because the highly productive physician continued his prolific scientific publishing and research well into the 1950s. During the 1950s, he began collaborating with Karl Storz in the development of instrumentation.

Another landmark in the 1930s occurred when the Hungarian physician Janos Veress developed a novel spring-loaded needle in 1937. The needle was originally used to perform therapeutic pneumothorax to treat patients with tuberculosis. However, laparoscopists quickly realized its potential for safe creation of pneumoperitoneum.[8]

Meanwhile, back in America, John Ruddock (1891–1961), an internist from Los Angeles, was most likely the principal driving force behind the acceptance of laparoscopy in the United States during the 1930s and beyond. Ruddock was known to work tirelessly to advocate for the laparoscope and to make a plea to internists and surgeons to work more cooperatively toward the goal of bringing minimally invasive care to patients. With his "peritoneoscope," he was able to diagnose patients with metastatic gastric carcinoma by minimally invasive means, sparing them a nontherapeutic and thus wasted laparotomy because metastatic disease was considered nonoperable at the time.

By the end of the 1930s, operative laparoscopic procedures were finally in more general clinical use and were no longer restricted to a few dedicated centers. However, parallel with this development were rising death rates from endoscopy complications. Some of the early pioneer physicians were visionary enough to comment on "the need for doctors to essentially retrain themselves" as an important impediment to general acceptance of laparoscopy.

Out in the Cold: The 1940s to the Mid 1960s

The increasing rate of deadly complications associated with rising use of laparoscopy was likely the reason that a 25-year gap in development took place in the United States between 1939 and 1966.[8] Fortunately, the development continued in Europe, with the Swedish-born French gynecologist Raoul Palmer (1904–1985) achieving brilliant milestones. During the early 1940s, in occupied Paris during World War II, he discovered the benefits of the Trendelenburg position for pelvic visualization. He developed safer administration of insufflation gases; video capture of procedures; and not least, excelled in the training of innumerable disciples from all over the world. Many of the great laparoscopists of the 1960s through the 1980s were trained by Palmer, who apparently was a generous and beloved teacher and mentor.

Unfortunately, the development of laparoscopy was not straightforward. In 1961, it suffered a great fall from grace when its use was banned in Germany as a "prohibitively hazardous procedure," a result of faulty insufflator and electrocautery units. By 1964, the ban was lifted because of improvements in component technology, but its reputation was nonetheless damaged.

Controversy Galore: The 1970s to the 1990s

For 21st century laparoscopic surgeons, the controversy surrounding laparoscopy as late as the 1980s and 1990s seems unbelievable. One of the remarkable pioneers, who persevered despite a massive storm of criticism, was the gynecologist Kurt Semm (1927–2003). In the 1970s, his innovations included the electronic insufflator, whose capability to precisely monitor intraabdominal pressures greatly increased the safety of pneumoperitoneum. He all but eliminated thermal injuries by improving radiofrequency electrosurgical techniques. He pioneered extra- and intracorporeal knot tying and invented the loop applicator.

In 1980, he performed the first laparoscopic appendectomy. No one could believe this was possible, and he was accused of pathological hoaxing. At the time, the gap between surgeons and gynecologists was immense. Semm's entrance into general surgery was seen as an attempt by a gynecologist to bolster his "operation ego".[1,6] All of his attempts to publish on his surgical technique were refused with the reasoning that such "nonsense will never belong to general surgery" or that it was "unethical." Even Semm's gynecologic colleagues thought he had gone too far and attacked his publications as being faulty and biased. The insulting criticism often went to extremes; the projector was unplugged during his presentations, with the motivation that unethical surgery was presented. After Semm lectured on laparoscopic appendectomy, the president of the German Surgical Society wrote to the Board of Directors of the German Gynecological Society suggesting suspension of Semm's license to practice medicine.

Camran Nezhat (1947–), a laparoscopic surgeon affiliated with Stanford University Medical Center in Palo Alto, California, and with the University of California San Francisco, is another such persevering pioneer.[2] He developed video laparoscopy, which removed the need for the surgeon to look directly through the eyepiece of the scope (Figure 0-2). This was a milestone and a pre-

Figure 0-2 Laparoscopy performed in 1974, before the introduction of video laparoscopy. (Courtesy of Dr. David C. Twedt.)

requisite for the laparoscopic revolution that followed; a surgeon simply cannot perform advanced procedures crouched over an eyepiece. His development also made him one of the most controversial figures in the movement of minimally invasive technology. Opponents of MIS accused laparoscopists like Nezhat of hiding their complication rates and advancing dangerous methods for personal gain. A couple of high-profile lawsuits in the early 2000s triggered nationwide media coverage, as Nezhat was accused of medical malpractice and racketeering. Both suits were dismissed, and the allegations were considered frivolous lawsuits in the one case; the attorney in the second was subsequently charged with contempt of court. Allegations of research fraud were made against Nezhat, all which were found to be unsubstantiated.

Fortunately, some surgeons saw these hard-earned achievements for their true value, and by the early 1990s, laparoscopic appendectomies were performed by these early adaptors in vast numbers. Shortly thereafter, the "laparoscopic revolution" broke out, and suddenly Semm's and Nezhat's expertise and publications were in great demand. Finally, in 2002, Semm received the Pioneer in Endoscopy Award from the Society of American Gastrointestinal Endoscopic Surgeons.[1] Nezhat also has won numerous awards and honors from prestigious societies such as the American College of Obstetricians and Gynecologists, American College of Surgeons, and Society of Laparoendoscopic Surgeons.

Small Animal Minimally Invasive Surgery

With the human laparoscopic physicians leading the way, small animal MIS has not been nearly as controversial as its human counterpart. Similar to the case in the medical field, MIS was fairly slow to be incorporated in general veterinary clinical practice. Our development appears to parallel that of human surgery but with an approximately 20-year delay. A "laparoscopic revolution" like that in the human medical field cannot yet be claimed by veterinary surgeons, but MIS is steadily moving the stakes forward with increasing use and improved surgical technique.

Early Work: The 1970s

The first reports on laparoscopy in small animals were conducted on dogs in the early 1900s, but these were mainly experimental models before application in humans. Similar to gynecologists, theriogenologists were among the earliest clinical adapters of MIS in research and clinical veterinary medicine during the 1950s and 1960s. However, in the early 1970s, work with diagnostic laparoscopy was emerging in the small animal field. Surgical application was sparse, but David E. Wildt, a non-DVM PhD affiliated with the Division of Research Services at National Institutes of Health, reported on male and female sterilization by occlusion of the vas deferens and uterine horn, respectively, in the early 1980s. Dr. Wildt coedited the first textbook in 1980 on animal laparoscopy together with Richard Harrison, PhD, at Tulane University.[4]

In 1977, the DVM Drs. Gerald F. Johnson and David C. Twedt (Figure 0-3), both at the time affiliated with the Animal Medical Center in New York, presented the first review of small animal laparoscopy for clinical use.[5] At that time, laparoscopy was exclusively a diagnostic tool (Figure 0-4), and nitrous oxide was the pneumoperitoneum gas of choice, especially if performed without general anesthesia. Air and carbon dioxide were also recommended, and the authors mention their preferred use of a Corkmaster (Figure 0-5), a carbon dioxide dispenser intended for opening wine bottles, adapted for generation of pneumoperitoneum.[5]

Figure 0-3 From left to right, Drs. Todd Tams, Steve Hill, and David Twedt are enjoying video laparoscopy in 1995. (Courtesy of Dr. David C. Twedt.)

Minimally Invasive Surgery Takes Off in Small Animal Surgery: The 2000s and Beyond

Arthroscopy was globally embraced by small animal veterinarians several years before the use of laparoscopy became widespread. From those early investigations in the late 1970s and 1980s, it would take another 2 decades before MIS would be commonly used for soft tissue applications in small animal surgery, the principal focus of this textbook. In 2009, the American College of Veterinary Surgeons added a requirement for MIS in resident training programs.

In 1999, Dr. Lynetta J. Freeman published *Veterinary Endosurgery*, the first textbook dedicated to application of MIS in small animals. To this day, this text remains a pioneering work because at that time, few clinical procedures had been described in dogs or cats, and the editor and her colleagues (Figure 0-6) shared their extensive clinical research and training experience

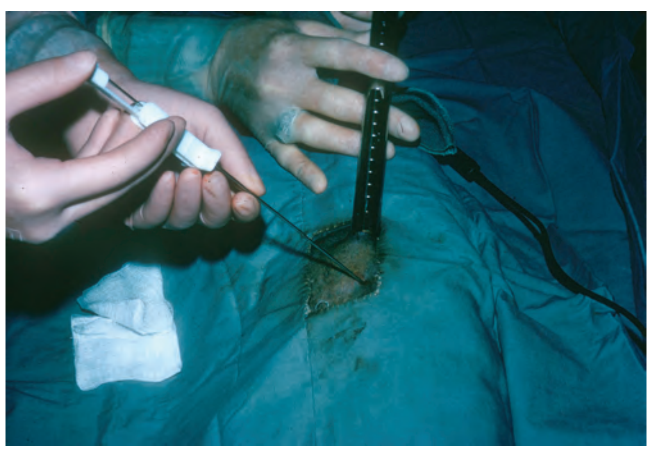

Figure 0-4 A proctoscope is used as a low-cost laparoscope for visualization of a liver biopsy in the 1970s. (Courtesy of Dr. David C. Twedt.)

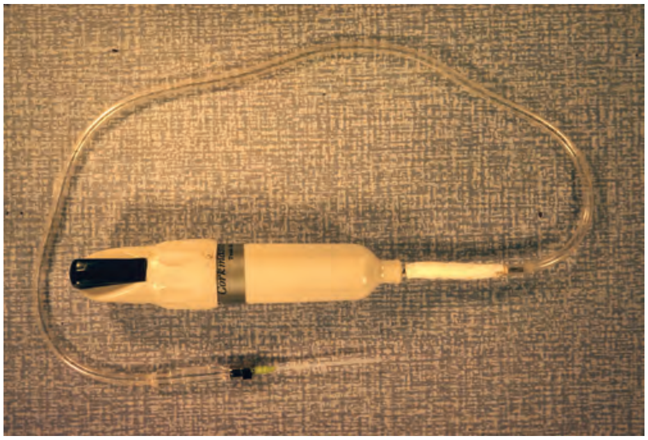

Figure 0-5 A Corkmaster, a carbon dioxide dispenser intended for opening wine bottles, adapted for generation of capnoperitoneum used by Drs. Twedt and Johnson in the 1970s. (Courtesy of Dr. David C. Twedt.)

from the research and development section of Ethicon Endosurgery.

Dr. Clarence A. Rawlings (Figure 0-7) and coworkers presented a series of publications in the early 2000s describing use of different laparoscopic-assisted surgical techniques. These continue to serve an important function today, bridging the gap between open and fully laparoscopic procedures. Dr. Rawlings is a pioneer of veterinary MIS and has been a dedicated instructor to hundreds of veterinarians interested in the field.

Small animal MIS has benefitted from an important advocate in Dr. Eric Monnet over the past 20 years. His contributions to the field have been imperative to clinical adaptation and development of laparoscopic and thoracoscopic techniques. In addition, Dr. Monnet's contributions also include founding the Veterinary Endoscopy Society (VES) (Figure 0-8) in 2003, bringing American veterinarians together with a common mission of promoting and developing minimally invasive techniques. Recently, the VES has reached out internationally, with the hope of expanding into a multinational community of veterinarians interested in the field.

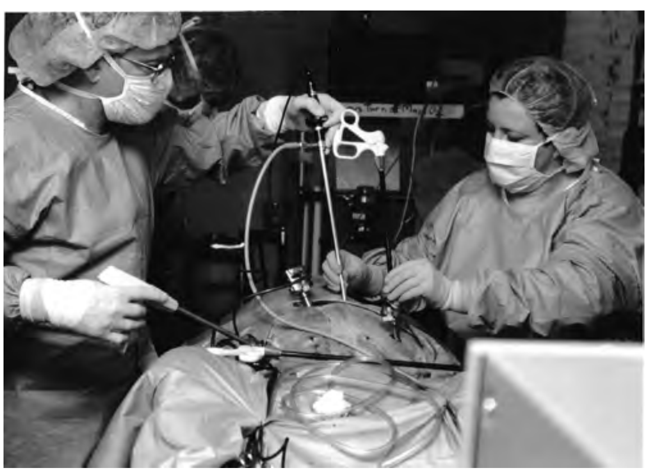

Figure 0-6 Drs. Lynnetta J. Freeman and Ronald J. Kolata are performing laparoscopy on a lion at the Audubon Zoo. (Courtesy of Dr. Lynneta J. Freeman.)

Figure 0-7 Dr. Clarence Rawlings. (Courtesy of Dr. Clarence A. Rawlings.)

Development of increasingly advanced clinical techniques is currently ongoing at a fast pace, and important contributions over the past decade have been made by Drs. Gilles Dupre, Philipp Mayhew, Jolle Kirpensteijn, Mary-Ann Radlinsky, Eric Viguier, and many others.

Lack of skills was noted as an important impediment to MIS development among our predecessors in the human field. Our research group at Washington State University has made important contributions to the veterinary MIS field within the area of assessment and training of veterinarians' manual skills.

A number of talented clinicians and researchers are currently active within small animal MIS. We anticipate further milestone achievements by these great men and women of our profession in the near future.

Figure 0-8 The Veterinary Endoscopy Society was founded by Dr. Eric Monnet in 2003.

Acknowledgements

Regretfully, many important contributors to the field were not mentioned in this text for the sake of brevity. Many pioneers contributed milestone developments and achieved glorious things despite technological limitations and often in a skeptical environment. To them, we collectively want to express our gratitude for their hard work paving the road to contemporary MIS. Thank you!

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SECTION I

Laparoscopic Skills

1 Surgeons' Skills Training

Boel A. Fransson, Heather A. Towle Millard, and Claude A. Ragle

Adding Minimally Invasive Surgery to the Surgical Repertoire

Since the introduction of laparoscopy and thoracoscopy in small animal surgery in the mid 1970s, the main focus has been on the development of surgical techniques and equipment. Not until recently has veterinary medicine recognized the importance of skills development for surgeons who want to incorporate minimally invasive surgery (MIS) in their clinical practice.

Even for surgeons with considerable expertise in traditional open surgery, it will be readily apparent when approaching MIS that some laparoscopic skills are distinctly different from those of open surgery. The challenges and differences include the use of long instruments, which magnifies any tremor and limits tactile sensation, often referred to as haptic feedback. When the instrument movement is limited by a portal into the body cavity, the surgeon needs to handle the resulting fulcrum effect and the loss of freedom to simply alter an approaching angle. But even more important, the normal binocular vision becomes monocular; as a result, the associated depth perception is lost. Other challenges include the loss of a readily accessible bird's eye view of the entire body cavity. The advantage of magnification may be perceived as offset by a reduced field of view, and any instrument activity outside the view becomes a liability.

Understandably, a surgeon who has performed hundreds or more of any given procedure, with good success and minimal time expenditure, may initially be reluctant to take on the challenges of MIS. This may be especially conspicuous in small animal laparoscopy, in which the conventional surgical approach provides excellent and easy access to all intraabdominal organs. A budding small animal laparoscopic surgeon may meet resistance from referring veterinarians and even staff members when converting open procedures to laparoscopic because costs and surgery time, at least initially, tend to be higher. Educating the referral base, clients, and staff in the advantages of laparoscopy may alleviate but not remove the initial resistance.

The solution to minimizing the surgeon's pains of transitioning from open to laparoscopic surgery consists of pretraining. The basic laparoscopic skills of ambidexterity, optimizing instrument interaction; observing cues for depth perception; and precise, deliberate movements need to be achieved early in the skills development for the benefit of patient safety and surgeon's confidence in the operating room (OR).

Basic Laparoscopic Skills

The basic skills required for laparoscopic surgery include ambidexterity, hand–eye coordination, instrument targeting accuracy, and recognition of cues to provide a sense of depth.[1,2]

Although these skills are used, and therefore trained, in clinical practice, the surgeon should not rely on caseload for training. The Institute of Medicine reported in "To Err Is Human" that approximately 100,000 humans die each year as a result of medical errors and that approximately 57% of these deaths are secondary to surgical mistakes.[3] Despite efforts to prevent surgery-related human deaths, the cost of training one surgical resident in an OR throughout the course of his or her residency is estimated to cost nearly $50,000.[4,5] and this is becoming cost prohibitive for teaching institutions. In addition, medical surgery residents are now limited to working 80 hours per week,[6] which further limits their exposure to clinical cases.

Although the number of surgical-related deaths in veterinary medicine in the United States is not known, they do occur. In addition, even though OR costs do not equal those of training a human surgical resident and we currently do not have limits on the work week of veterinary students or veterinary surgery residents, veterinary medicine has its own set of dilemmas. Veterinary training curricula are also faced with financial limitations, as well as increasing external and internal ethical concerns regarding the use of research animals for surgical training; increasing number of veterinary students being admitted to programs and subsequent decreased

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Companion website: www.wiley.com/go/fransson/laparoscopy

exposure to laboratory and clinical cases; lack of sustainability of cadavers because of problems with availability, storage, and limited usefulness because of decay; and the drive to reduce errors made by inexperienced surgeons on actual patients.[7,8] For these reasons, both human and veterinary educators are being compelled to develop innovative teaching methods for surgical skill instruction.

Beside the ethical and cost issues, it is likely that a training program built on practice in live patients becomes limited and inconsistent. Interestingly, we have noticed in our work that even experienced veterinary laparoscopic surgeons tend to lag in efficient use of their nondominant hands, something easily rectified by simulation training.[9] In fact, the basic skills are most efficiently trained through simulation training.[10] This has been recognized for more than a decade among medical doctors, and since 2008, laparoscopic simulation training curricula have been a requirement for surgery residency programs in the United States.[11] Robust evidence has been presented to demonstrate that skills developed by simulation indeed transfer into improved OR performance.[12-16]

Simulation Training Models

A number of simulation models have been presented and can currently be divided into three main categories: physical; virtual reality (VR); and hybrid, or augmented reality (AR), models.

Physical Simulation Models: Box Trainers

Box trainers have in common that tasks are performed using regular laparoscopic instruments in a box containing a camera, which projects onto a computer or TV screen. A number of box trainers are commercially available (Figure 1-1) and carry the advantages of being portable and highly versatile. As web cam technology has improved within recent years, homemade trainers can be a very cost-effective alternative if portability is not a requirement. An example of a homemade trainer used in the author's Veterinary Applied Laparoscopic Training (VALT) laboratory is presented in Figures 1-2 to 1-4. Homemade versions are used solely for practice and not for skills assessments.

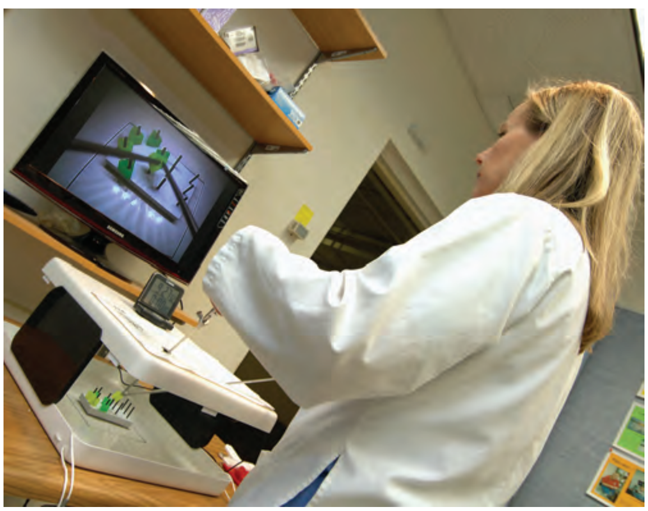

Figure 1-1 A number of laparoscopic skills training boxes are commercially available. Most are portable, and many have cameras that connect to a computer by USB connections. Some, including the official box for Fundamentals of Laparoscopic Surgery, require a TV screen. (Photo courtesy of Henry Moore, Jr., Washington State University, College of Veterinary Medicine.)

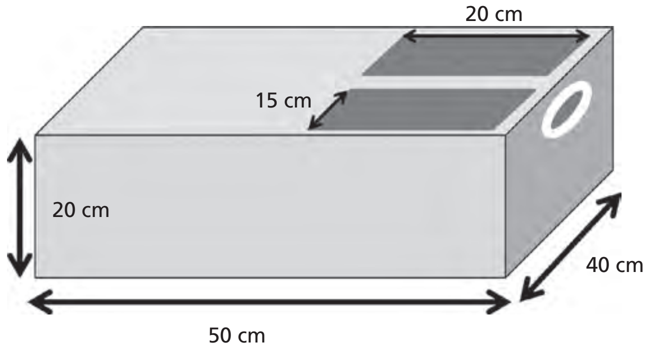

Figure 1-2 Commonly used dimensions in laparoscopic training boxes.

Box training can be considered low-fidelity simulation (i.e., less lifelike but nonetheless highly efficient training tools). A number of practice drills have been developed and validated. In the 1990s, several structured training tasks were described, including the Dr. Rosser's station tasks developed at Yale University, which are part of the popular "Top-Gun Shoot-Out" competition at national meetings for physicians. The physical training task system with the most solid validation to date is the McGill Inanimate Simulator for Training and Evaluation of Laparoscopic Skills (MISTELS).[10,17-19] At present, MISTELS includes peg transfer, pattern cutting, ligature loop placement, and intra- and extracorporeal suturing. An additional cannulation task is currently being incorporated.[20]

We have considerable experience of MISTELS-type training of veterinarians in our simulation training facility, the VALT laboratory

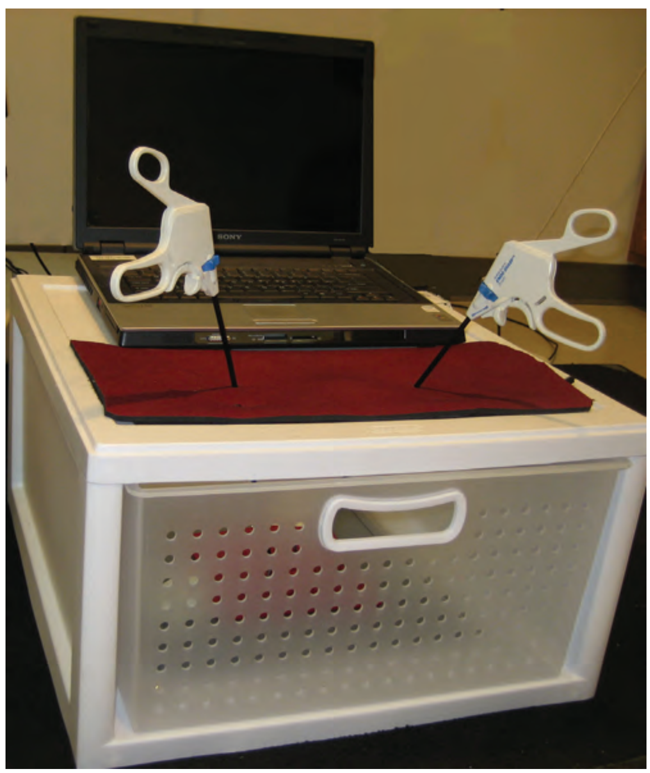

Figure 1-3 An example of a homemade training box.

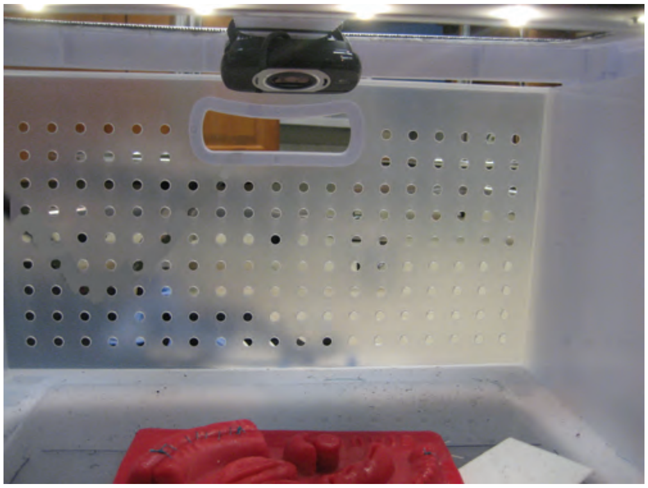

Figure 1-4 Recent advances in web cameras enable real-time imaging to a low cost.

(Figure 1-5) at Washington State University. The adaptation of MISTELS for the VALT laboratory has been described in detail elsewhere,[9,21] and currently, the tasks we use include:

1 **Pegboard transfer:** Laparoscopic grasping forceps in the nondominant hand is used to lift each of six pegs from a pegboard, transfer them to a grasper in the dominant hand, place them on a second pegboard, and finally reverse the exercise (Figure 1-6).

2 **Pattern cutting:** This task involves cutting a 4-cm diameter circular pattern out of a 10 × 15-cm piece of instrument wrapping material or a gauze suspended between alligator clips (Figure 1-7).

3 **Ligature loop placement:** The task involves placing a ligature loop pretied with a laparoscopic slip knot over a mark placed on a foam appendix and cinching it down with a disposable-type knot pusher (Figure 1-8).

Figure 1-5 Logotype for the Veterinary Applied Laparoscopic Training laboratory at Washington State University.

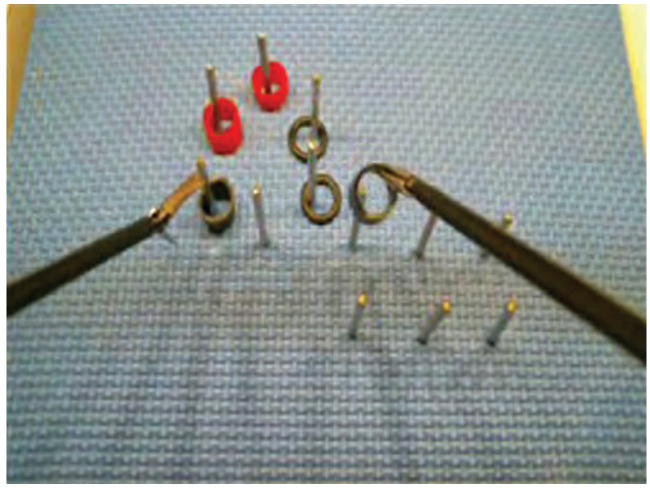

Figure 1-6 Peg transfer task. Six objects are lifted from the left-sided pegs with nondominant grasper, transferred midair to the dominant hand grasper, and then placed on a right-sided peg. The exercise is then reversed.

4 **Extracorporeal suturing:** A simple interrupted suture using long (90-cm) suture on a taper point needle is placed through marked needle entry and exit points in a slitted Penrose drain segment. The first throw in the knot is tied extracorporeally with a slip knot and cinched down by use of a knot pusher. Thereafter, three single square throws are placed by use of laparoscopic needle holders and the suture is cut (Figure 1-9).

5 **Intracorporeal suturing:** A simple interrupted suture is placed using short (12- to 15-cm-long) suture on a taper point needle through marked needle entry and exit points in a slitted Penrose drain segment. Three throws are placed, the first being a surgeon's (double) throw, by use of laparoscopic needle holders. The exercise is completed when the suture is cut (Figure 1-10).

In addition to the MISTELS exercises, we have found important benefits in the VALT laboratory of a variety of exercises, which have been presented.[9] We find that exercises performed in a simulated canine abdomen (Mayo Endoscopy Simulated Image, Sawbones,

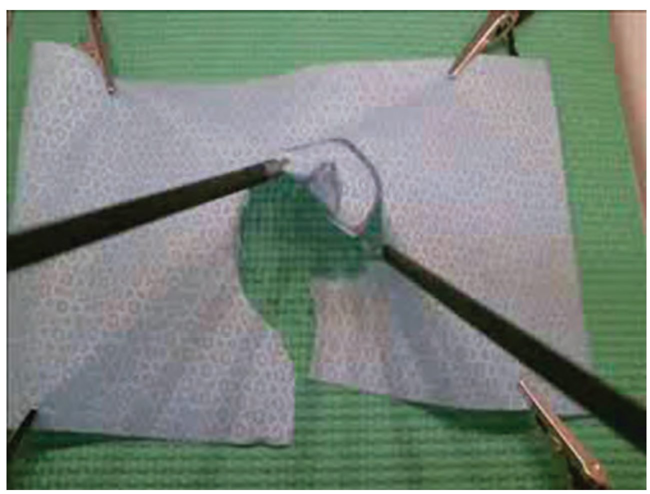

Figure 1-7 Pattern cut task. A 4-cm circle is cut, with a penalty applied if the cut is outside the mark.

Figure 1-8 Ligature loop application task.

Vashon, WA; Figure 1-11) can be helpful in practicing camera manipulation and mirroring situations (i.e., camera facing surgeon) and can help prepare the surgeon for the confines of a canine abdomen.

The one major disadvantage with box training is the lack of instant feedback. Without automated feedback, an experienced surgeon needs to be available to critique the performance of the trainee, which becomes an important limitation because of the busy schedules of most surgeons. However, proficiency goals have been defined for MISTELS such that the trainee can monitor his or her progress by simple metrics such as time and errors.[22] With these goals in mind, the trainee can practice independently for the basic tasks of peg transfer, pattern cutting, and ligature loop placement. Laparoscopic suturing requires instructive sessions with an experienced surgeon. When suturing technique has been learned, the trainee can continue to practice independently to reach an expert level of performance, as defined by the proficiency goals.

Another disadvantage of box training is the current lack of veterinary high-fidelity surgery procedural models. Physical models

Figure 1-9 Extracorporeal suture task.

Figure 1-10 Intracorporeal suture task.

for cholecystectomy, appendectomy, and so on are commercially available, but they are all fairly expensive. In addition, they are all based on human anatomy and physiology and thus are less relevant for veterinary surgeons. A physical model, which can often be used only once, may not be feasible for most residency training programs if the cost is more than $100/each. Research into construction of low-cost yet higher fidelity physical models is ongoing at our institution, which may provide increased access to veterinary procedure models in the future.

Virtual Reality Simulation

Highly realistic VR simulation (Figure 1-12) is commercially available for both basic skills as well as entire simulated surgical procedures. In fact, one of the main advantages with VR training is realistic simulation of surgical procedures, which is hard to achieve to a reasonable cost in box training. For veterinarians, this advantage is somewhat limited, though, because anatomy and surgical procedures are all based on human anatomy.

Basic task simulations give the trainee opportunity to experience a variety of surgical complications, such as bleeding, dropping clips, and repercussion from rough tissue handling while benefiting from

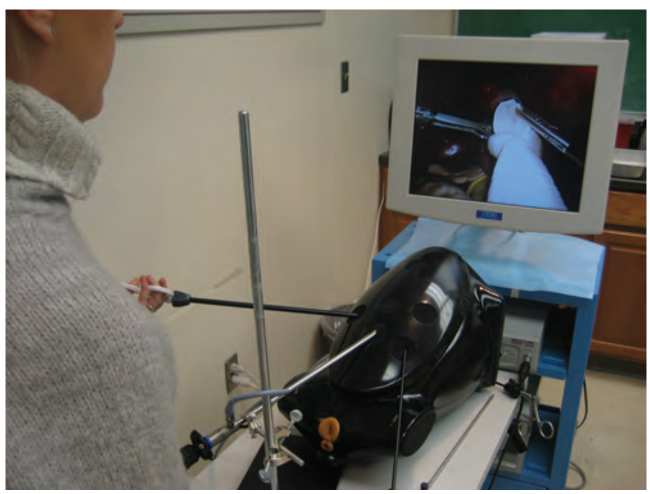

Figure 1-11 The Mayo Endoscopic Simulated Image (MESI) canine model (Sawbones, Vashon, WA) for laparoscopic and endoscopic practice.

Figure 1-12 The ProMis augmented reality trainer is a combination of a physical box trainer and a virtual reality overlay used in many surgical exercises. (Photo courtesy of CAE Healthcare, © 2014 CAE Healthcare.)

instant feedback and suggestions on how to proceed. Other advantages of VR simulation are that modules contain detailed instruction for performance of all tasks and summative feedback comparing the overall performance with an expert level. The summative performance is also broken down into a number of performance metrics, such as time, instrument path length for the dominant and non-dominant hands, and errors, giving objective information about the performance. Therefore, the provided feedback of VR gives the trainee opportunity to practice without the need for an instructor. We have found that this instant feedback also serves as motivation because most surgeons and residents have competitive personalities and enjoy the comparison with expert level.

At present, a number of VR simulators are commercially available, but they all carry the disadvantage of being expensive. For example, a haptic LapSim (Surgical Science, Minneapolis, MN) unit currently cost a little over $90,000 (personal communication, Tony Rubin, VP, Surgical Science, Inc., September 2013), and software updates are also expensive. Another disadvantage is that, as mentioned, all VR simulation is based on human anatomy, and developing software for veterinary simulation is expensive; such models may not become available, at least not in the near future.

Because of the high cost of VR training, investigations have tried to determine if VR training can be justified by being more effective than box training. A recent systematic review through the Cochrane Institute found that VR procedural training shows some advantage over box training in operating time and performance.[23] Some controversy seems to exist: a similar review concluded that VR and box training both are valid teaching models and that both methods are recommended in surgical curricula but with no definitive superiority of VR.[24] Important for veterinary conditions, VR procedural training may not be superior unless it is procedure specific,[25] and thus it likely needs to be species specific.

Currently, the VALT laboratory group is studying the effects of incorporating VR basic skills or surgical procedural skills into the

Figure 1-13 The LapSimHaptic system virtual reality trainer is combining high-technological virtual reality exercises with haptic feedback. (© Surgical Science Inc. Reproduced with permission from Surgical Science Inc.)

physical training curriculum, and this information will be available in the near future. Preliminary data do not support that VR cholecystectomy training translates to performance on a physical cholecystectomy model.

Hybrid Training Models: Augmented Reality

Virtual reality simulation has been criticized for the lack of realistic haptic feedback[26]; therefore, hybrid, or AR, simulators were developed that combine a live and a virtual environment. A number of AR simulators are commercially available.[27] To date, the most validated system is the ProMIS simulator (CAE Healthcare, Montreal, Quebec; Figure 1-13), which has been used in the VALT laboratory since 2010. Tasks are performed in a box trainer using real instruments, but a virtual interface can be placed over the image of the camera. Three cameras are used for motion tracking of the physical instruments in three planes. Therefore, objective metrics such as instrument path and economy of movement (i.e., velocity and directional changes over time, also expressed as motion smoothness) are provided. The metrics used have showed construct validity in suturing tasks and in the ability to separate expert colorectal surgeons from experienced laparoscopic, but novice colorectal, surgeons.[28,29]

In our experience, the use of surgical instruments adds realism to the simulation, which is in agreement with a study comparing AR with VR simulation.[30] However, an even bigger advantage for veterinary surgery is the ability to use novel physical models for simulation. Species-specific models can be custom made and used in the ProMIS, obtaining motion metrics feedback. Until species-specific simulation in VR is developed, this will likely be the most useful procedural simulation training device. The VALT laboratory is currently working on development of realistic simulation models made from materials of reasonable costs. Unfortunately, availability of the ProMIS simulator is currently reduced because the manufacturing company recently changed, and production is temporarily on hold.

Video Games in Laparoscopic Skills Training

Bench-top models, VR simulators, medical simulators, and robotic surgical systems have been investigated extensively in the human medical field. Although these systems have proven effective, they can be costly and time consuming to set up and maintain. Video gaming is a multi-billion dollar industry. In 2014, it was estimated that 59% of Americans play video games, with 52% of gamers being male and 42% of gamers being female. Twenty-nine percent of gamers are younger than 18 years old, 32% are 18 to 35 years old, and 39% are older than 36 years old.[31] This surge in the availability and the creation of new video games that have motion-sensing interfaces that allow gamers to move the controllers through three dimensions have led to an increasing interest in the usability of video games to aid in surgical training. Video games are portable, do not necessitate the use of a specialized skills laboratory, are easy to set up and use, and can be used within small spaces, and no consumables are associated with their use.

Contemporary video game consoles use similar skills as laparoscopic surgery in that they improve precision and accuracy of hand movements, two-hand coordination, and conversion of three-dimensional movements to a two-dimensional screen.[32] They require depth perception, timing, visual-motor dexterity, and quick reflexes.[33] Studies have shown that individuals who grew up playing video games have faster reaction times and improved performance on hand–eye coordinative tasks, spatial visualization tasks, and neuropsychological tests.[6,34-37] Video games have also been proven to enhance visual selective attention capacity[37] and to increase response time to visual stimuli.[38] Green and Bavalier[37] found that gamers have improved abilities to take in peripheral detail while still focusing on the specific task at hand; this is called "flanker compatibility task." Compared with nongamers, they also found that gamers have greater attention to detail as task difficulty increases and an increased ability to perform better at task switching and enumeration tasks. Green and Bavelier questioned if students who played video games had a natural inclination toward these skill sets or if playing video games actually increased performance. To test this, they had nongamers play video games for 1 hour per day for 10 days. Nongamers were able to improve their visuospatial task scores, thus rejecting the notion that video gamers do better because of a natural aptitude.[37] Last, video games have the added benefit of reducing stress among students while also being competitive and entertaining.[8,38]

Proof of Utility of Video Games

The positive correlation of performance with laparoscopic box trainers and surgical simulators to improved operative laparoscopic performance has been demonstrated repeatedly in human medicine.[14,22,33,39] Although hands-on training is ultimately required for complete training, video games may provide a useful precursor or adjunct to laparoscopic box trainers and surgical simulators. However, proof of the utility of video games must be demonstrated before incorporating video games into surgical training programs. Within the past decade, the human field has also published numerous studies demonstrating the positive correlation between video game performance and laparoscopic box trainers, surgical simulators, and actual OR performance. Few studies currently exist in veterinary medicine. The following studies are just a glimpse of the benefits of using video games.

Badurdeen *et al.*[40] recruited 20 medical students and junior doctors with minimal laparoscopic surgical or video game experience. They found a positive correlation with video game scores and laparoscopic box-training skills ($r = 0.78$). In fact, participants scoring in the top tertile for video games scored 60.3% higher on laparoscopic box trainers than the bottom tertile ($P < 0.01$).

Boyle *et al.*[41] recruited 22 medical students without previous laparoscopic or video game experience. Baseline laparoscopic box-training skills were obtained. Then half of the students were allocated to continue to not play video games while the other half was allocated to play for 3 hours. All participants then returned in 5 to 7 days to retest their laparoscopic skills. Those with just 3 hours of video game experience scored better than those that did not play.

Adams *et al.*[6] obtained baseline laparoscopic simulator scores and then randomly allocated 31 surgical residents to 6 weeks of practice on a laparoscopic simulator, XBOX 360 (Microsoft Corp., Redmond, WA) or Nintendo Wii (Nintendo of America, Redmond, WA). At the end of the 6 weeks, all participants were retested on the laparoscopic simulator. Quite interestingly, participants who played the XBOX 360 or Nintendo Wii improved the most.

Grantcharov *et al.*[42] surveyed 25 surgical residents with and without past video game experience. Those with past video game experience of varying levels made fewer errors than nonusers in the OR ($P = 0.035$).

Shane *et al.*[43] found that fourth-year medical students who played more than 3 hours of video games per week had improved laparoscopic simulator scores and shorter learner curves than nongamers.

Rosser *et al.*[44] found that surgeons who play video games for more than 3 hours each week were 27% faster, made 37% fewer errors, and scored 42% better overall than surgeons who had no video game exposure with laparoscopic operative skills and suturing. Current video game players were 24% faster, made 32% fewer errors, and scored 26% better overall than their nonplayer colleagues. Past and current video game skill not only increased speed but also decreased errors.

Towle Millard *et al.*[8] published the first veterinary study correlating video game performance and laparoscopic skills. Twenty-nine third-year veterinary students volunteered to participate in the study; they all had varying levels of past video game experience. However, none of the participants had previous experience with the three test video games or the three laparoscopic box-trainer tasks. The study clearly demonstrated a positive correlation between video game proficiency and laparoscopic box-trainer proficiency ($r_s = +0.40$, $P = 0.031$).[8]

Future Incorporation of Video Games Into Training Programs

The studies just discussed are just a few of the many studies that demonstrate the positive correlation between past and current video game experience and improved scores on laparoscopic box trainers, laparoscopic surgical simulators, and laparoscopic operative performance. Additional veterinary studies are needed, but one could surmise that the results will likely be similar to those in the human medical field. Now that the link has been made, educators can explore methods to incorporate video games into helping students discover natural aptitudes and advancing surgical training before they enter the OR.

Kennedy *et al.*[36] recently proposed that video games may be useful for identifying and assessing natural aptitudes. Studies have been conducted on high school students, medical students, medical surgery residents, and veterinary students. Video games may be a method to help direct students into discovering hidden talents and help direct them to future career paths. Towle Millard and Freeman[45] surveyed 68 third-year veterinary students. They found that the 38 students with a higher interest in surgery had higher video game scores ($P = 0.023$) than the 30 students with a higher interest in internal medicine. Interestingly, Fanning *et al.*[46] found that teenagers with video gaming experience performed better on laparoscopy simulators than medical surgery residents with no gaming experience. Kennedy *et al*.[36] found that medical students who average 7 hours of video gaming per week had better psychomotor skills than those who did not play regularly. Shane *et al.*[43] found that medical students and first-year surgery residents with previous and current video gaming experience took fewer trials to gain proficiency on a laparoscopic simulator than did nongamers. Badurdeen *et al.*[40] suggested that the surgical residents who perform better on video games could be viewed more positively when selecting suitable surgery candidates to advance to laparoscopic training programs.

Besides helping identify promising young students and incorporating video games into training programs before entering the OR, video games may also be used as a "warm-up" method before starting surgeries to decrease the number of OR complications. Gallagher *et al.*[47] and Gallagher and Satava[48] demonstrated that 15 to 20 minutes of warm-up with simulators resulted in fewer OR errors in both fresh and fatigued surgeons. Rosser *et al.*[34] demonstrated that the use of video games just before performing surgery resulted in faster surgeons who made fewer errors versus surgeons who did not warm up. Using video games as a warm-up method is just another benefit of this cost-effective, motivational, and highly available resource.

Conclusion

Medical and veterinary educators are compelled to develop innovative methods to teach surgery as they are faced with expanding curricula, more students, financial constraints, limited time, and increasing ethical concerns of inexperience students and surgeons operating on actual patients. The traditional approach of "learning by doing" in a clinical arena is falling out of favor in both human and veterinary surgery.[49] The current social climate in human medicine is that novices should not gain their basic skills on actual patients, and this is extending to veterinary medicine as more and more veterinary owners think of their small animal pets as family members.

Although box trainers and surgical simulators are obvious training modalities, video games are an underused modality that is inexpensive and has been shown to directly correlate with box trainers, surgical simulators, and OR performance. As the technology advances, video games can be designed that directly simulate laparoscopic surgery. These modalities will not completely replicate actual OR experiences, but using them could be part of the solution of improving patient outcomes and addressing the dilemmas faced by teaching institutions.

The Optimal Training Program

Extensive amounts of research have provided comprehensive information on training program design. What follows is a brief discussion of current evidence-based information, with comparative aspects with our experience of veterinary training in the VALT laboratory.

Ideally, training initially focuses on basic skills task training before progressing to specific surgical procedure training. More important than the type of simulation model one has access to is that the practice is deliberate.[50] Expertise is not gained by simply spending time practicing but by engaging in a specific type of practice. The concept of deliberate practice[50] outlines the critical elements of optimal learning, that is, tasks with (1) well-defined goals, (2) motivation to learn, (3) feedback, and (4) opportunities for repetition and refinement.

Tasks and Goals

Training tasks can be selected based on construct validity (i.e., tasks in which performance has been demonstrated to correlate with higher skill levels). However, face value is also important (i.e., experienced surgeons confirming that a training task is using the same skill sets as those required in clinical practice). All tasks need to be demonstrated clearly and effectively for superior learning. Ideally, trainees have unlimited access to high-quality video tutorials and demonstrations, complementing and significantly decreasing the need for expert instructor involvement.[51]

Training goals in form of performance targets are generally accepted as superior to time-based training because individuals may differ considerably in how fast the target is reached. For MISTELS-based training, performance goals have been clearly defined.[22] For other practice tasks, speed, accuracy, or even motion metrics have shown severe limitations, and appropriate training goals for trainees at different levels of training remain work in progress.[51] A training study in the VALT laboratory failed to document advantages of proficiency goals compared with time control,[9] and this observation has also been made by others.[52] Perhaps as the medical field learns more about simulation training, we will become increasingly successful in setting appropriate goals. Despite our experiences in the VALT laboratory, we consider proficiency goals valuable because we have noted that training goals appear to add motivation to practice.

Motivation

Internal motivation is a prerequisite for learning but cannot be relied on as the sole driving source for a successful training program. Surgical residents and practicing surgeons are affected by long working hours, limited free time, and seemingly endless clinical responsibilities. Not surprisingly, studies on voluntary participation of skills training in a busy residency showed the participation rate as between 6% and 14%.[53,54] These studies showed that providing dedicated regular time for mandatory training, known ahead of time to trainees and their faculty, greatly improved participation. For a laboratory with limited resources, this may be hard to accomplish. In the VALT laboratory, we have had success with mandatory training sessions but with timing flexibility through an online sign-up policy, so each trainee can choose the time that works best for him or her without affecting the clinic or crowding the laboratory. The importance of dedicated laboratory personnel, keeping track of the trainees' sessions, and the commitment from faculty in supporting the training cannot be stressed enough. In addition, external motivation can be gained from training feedback and scheduled skills assessments. Further external motivation may be gained by performance requirements on simulators before OR participation,[51] but we have not yet felt a need for that at the VALT laboratory. Importantly, we have found an inverse relationship between motivation for simulation training and clinical experience,[9] underscoring the importance of initiating simulation training early in a laparoscopic surgeon's career.

Feedback

Regular feedback during simulation training is not only a tool for motivation but is also essential for skills acquisition and retention. As already discussed, motion metrics serve as instant feedback during VR training and are likely one of the most important advantages to that type of simulation training. However, verbal feedback from experts has been shown more effective than motion metrics.[55] Specific and individualized feedback and subsequent training tailored to address that feedback have recently been shown to greatly improve OR performance.[56]

Opportunity to Practice

Currently, the opportunity for simulation training is severely limited for veterinary surgeons and residents. Hopefully, veterinary surgery will show a similar development to that occurring over the past decade among MD surgeons. In 2006, only 55% of residency programs had training laboratories,[57] but by 2008, such laboratories became a requirement.[11] Currently, the VALT laboratory offers training for external DVMs, but ideally, residents should have easy access to simulation training at their home institutions and practices. This preference is based on the fact that distributed practice leads to better skills acquisition compared with intense extended practice.[51] The optimal distribution is presently considered to be 1-hour sessions with a maximum of two sessions per day interspersed by a rest period, allowing the brain the opportunity to internalize the learning.[58] Approximately 10 hours of practice has been demonstrated to lead to fundamentals of laparoscopic surgery (FLS) competency,[22] but mastery within any given field requires approximately 10,000 hours of deliberate practice.[58] Skill decay will ensue after rigorous training, but with ongoing practice in small amounts at 6-months intervals, performance has been shown to be maintained at a high level.[58]

Self-training

Most veterinarians in practice do not and will not have easy access to simulation training curricula. Fortunately, MISTELS type exercises lend themselves well to self-study because there are well-defined training goals that are easy to monitor. Self-study guidelines based on performance time have been demonstrated, showing that reliable achievement of 53-s peg transfer, 50-s pattern cut, 87-s ligature loop, 99-s extracorporeal suturing, and 96-s intracorporeal suturing times are associated with an 84% chance of passing the FLS test,[59] thus demonstrating basic skills competency. Laparoscopic suturing will likely require training proctored by experienced surgeons, and we encourage self-study trainees to seek instruction for those exercises. Presently, there is a move to make video-tutorial training material and a manual skills test, Veterinary Assessment of Laparoscopic skills (VALS), also available for veterinarians. The VALS program is based on the rigorously validated MISTELS program for training and assessment of skills. The goal is to create a readily available training program for all veterinary surgeons, leading to improved OR performance. A 5-week systematic video game training program showed a positive impact on subsequent performance on complex surgical simulator tasks.[60] Such a rigorous video gaming program could be readily available to surgeons, and if routinely incorporated into VALS, constitute an inexpensive precursor or concurrent training modality.

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2 Minimally Invasive Suturing Techniques

Boel A. Fransson and John C. Huhn

Key Points

- Laparoscopic intracorporeal suturing requires simulator training until the motion is fluent and automatic. There will be added challenges in the operating room (OR), and if the skill is not fluent in the simulator, clinical suturing will be near impossible.
- Sutures longer than 30 cm (12 in) are extremely challenging for intracorporeal suturing.
- Learn to identify clockwise and counterclockwise wrapping of suture to ensure square knots during intracorporeal suturing.
- For intracorporeal continuous suturing, barbed sutures are outstanding.
- Extracorporeal suturing requires a long suture, ideally exceeding 75 cm (30 in), and a knot pusher in addition to needle driver and grasper.
- For braided sutures, the knot is complete with three throws. However, for monofilament sutures, four to six throws are required for knot security.
- The ability to tie one or more types of slip knots for extracorporeal use is a useful skill for minimally invasive surgeons. As with intracorporeal suturing, the conditions in the OR tend to be more challenging, so make sure you make the slip knots with ease outside the OR.
- Most extracorporeal slip knots require added throws performed with intra- or extracorporeal technique to be secure.
- Automated suturing devices, including the Endo Stitch and the SILS (single incision laparoscopic surgery) Stitch device, are preferred by many surgeons.

Introduction to Laparoscopic Suturing

In the early years of minimally invasive surgery (MIS), controversy existed regarding the need for suturing skills. Many practicing surgeons thought that laparoscopic suturing was too difficult to ever be considered a realistic requirement.[1] However, in the early 1990s, a consensus was built: laparoscopic surgeons had to learn and apply basic suturing skills unless the development of laparoscopic surgery was to be impeded.[2] Soon it was recognized that these complex skills had to be practiced with other methods than the classical "see one, do one, teach one" paradigm of conventional residency training. As a result, simulation training became a requirement.

Currently, veterinary medicine is facing the same dilemma. The introduction of MIS into small animal surgery has resulted in MIS technology being available at most specialized and many nonspecialized practices. For progressive evolution of small animal MIS, we need to embrace suturing techniques. Because of the challenge of suturing, many replacement devices have been introduced, but most are expensive and not always as versatile or secure as desired. With suturing skills, many open surgical techniques can be replaced with minimally invasive counterparts for the benefit of our patients. Having suturing skills also increases the surgeon's confidence to deal with emergent situations during a surgical procedure without the need for conversion to open surgery.

This chapter is intended to give novice laparoscopic surgeons a foundation, enabling them to start practicing suturing in a simulator in preparation for clinical application. With suturing skills developed in the simulator, we have found that the step to intracorporeal clinical suturing is small for most trainees.

Needle Holders for Laparoscopic Suturing

Conventional laparoscopic needle holders differ from most other laparoscopic instruments in that they do not rotate around the axis of the instruments in order to provide stability. Articulating and rotating needle drivers have been introduced but have been criticized for creating imprecision in needle exit and for being more difficult to learn to use than conventional needle drivers.[3]

The handles are often of a straight axial design, placing the needle in line with the surgeon's hands to allow greater maneuverability and more natural motion of the wrist when suturing. The jaws are often single action and are usually operated by means of an ergonomic spring-loaded palm grip on the handle.

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Companion website: www.wiley.com/go/fransson/laparoscopy

Figure 2-1 Pistol grip laparoscopic needle driver. (© 2014 Photo courtesy of KARL STORZ GmbH & Co. KG.)

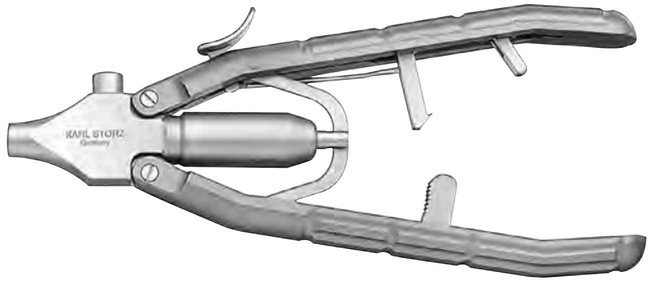

Figure 2-3 For novice laparoscopic surgeons, we recommend needle drivers that are sturdy, with straight handles, ribbed grips, and conveniently located needle release buttons on the grips. (© 2014 Photo courtesy of KARL STORZ GmbH & Co. KG.)

Several handle types are available, and the efficacies of four of them were compared.[4] It was found that a pistol grip (Figure 2-1) was superior for experienced operators but not for novices, who preferred a palmed straight grip. Neither experienced or novice users performed well nor preferred a thumb–ring finger grip (Figure 2-2).[4]

For novice laparoscopic surgeons, we recommend a needle driver that is sturdy, with straight handle, a ribbed grip, and a conveniently located needle release button on the grip (Figure 2-3). Hand size differs among surgeons; therefore, the preferred position of the release button may differ. When the release button is placed in the axis of the instrument, it can be used with either hand.

Needle driver jaws may be straight, curved left, or curved right (Figure 2-4). They can also be self-righting. Straight jaws are this author's (BAF) preference because they can be used in both left and right positions. The jaws are designed for a particular range of needle sizes, which is important to note before purchase. Self-righting needle drivers force the needle into a fixed position, usually at 90-degree angle to the instrument shaft. The limitations of self-righting needle drivers is that they should not be used to grasp the suture because they may damage or weaken the material. In addition, they reduce the surgeon's freedom to position the needle in different angles.

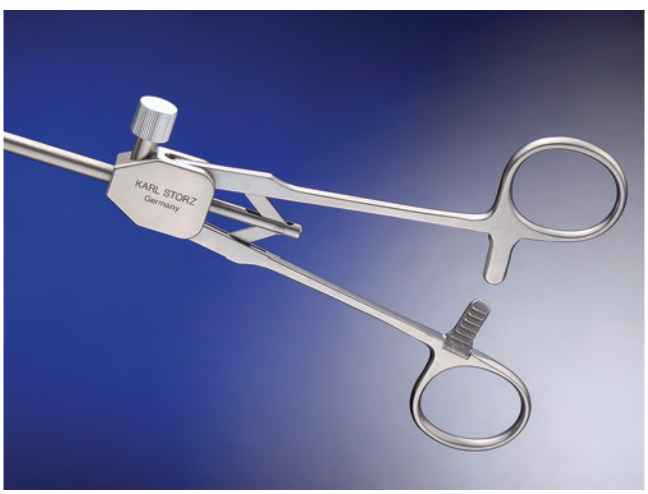

Figure 2-2 Needle driver with handle designed for thumb–ring finger grip. These did not perform as well as other designs.[4] (© 2014 Photo courtesy of KARL STORZ GmbH & Co. KG.)

Suture Materials for Minimally Invasive Suturing

Conventional Sutures

Conventional suture materials are routinely used in MIS (Table 2.1). Braided synthetic absorbable sutures are often favored over monofilament synthetic absorbable sutures for intracorporeal suturing. The primary reason for this preference is the ease of handling that follows from the decreased memory of braided versus monofilament sutures. Furthermore, braided sutures are more resistant to instrument-induced damage during the knotting process. As knots are formed, there is significant interstrand friction, commonly known as chatter. This friction can induce significant damage to suture materials, particularly monofilaments. Braided materials are less vulnerable to this damage because their strength is distributed over many fibers similar to the cables of a suspension bridge. Braided materials are not without their downside, however. They have considerably more tissue drag than monofilament sutures, and they can harbor and potentiate bacterial infections. To minimize these effects, suture manufacturers have devised two solutions. First, application of coating agents, such as silicone, wax,

Figure 2-4 Different configurations of needle driver jaws. From top to bottom: "parrot jaw" curved left, "flamingo jaw" curved right for a 6-mm cannula, and "flamingo jaw" curved right for an 11-mm cannula. (© 2014 Photo courtesy of KARL STORZ GmbH & Co. KG.)

Table 2-1 Conventional Sutures Used in Minimally Invasive Surgery

	Tensile Strength	Memory	Absorption Profile[22,23]	Throws Required[5]
Braided				
Polysorb	++++	–		3–4
Vicryl	++++	–		3–4
Monofilament				
Monocryl	++	–		3–4
Biosyn	+++	—	90–110 d	4–5
Polydioxanone (PDS)	++	–		3–4
Maxon	+++	—	180 d	4–5

polytetrafluoroethylene (PTFE), caprolactone, and calcium stearate, fills in the gaps in the interstices of the braid and decreases friction during tissue passage. Second, some manufacturers use antimicrobial coatings on their materials to preemptively address suture-potentiated infections.

Knot security is a function of suture interstrand friction. Braided suture materials have a higher coefficient of friction than monofilament sutures. As such, braided sutures can form secure knots with fewer throws than monofilament sutures. In general, whereas braided sutures require three or four throws to form a secure knot, monofilament sutures require four or five throws.[5] Coated braided materials have less interstrand friction than their uncoated counterparts but still require fewer throws than monofilaments for stable knot formation.

Suture Needles

Conventional 1/2 and 3/8 suture needles are commonly used in MIS. Specialized half-curved ("ski") needles can be advantageous when operative space is limited. The J needle may be beneficial when closing port incisions. Straight needles can be used in special circumstances, but limited access precludes their general usage (Figure 2-5).

It is helpful to use needles that are flattened along their bodies to allow stable grasping with an endoscopic needle holder. Taper or tapercut points are best. Reverse cutting needles may be used, but one must be conscious of the cutting edge on the convex surface. Inadvertent cutting of vascular structures is possible because of poor visualization of the back side of the reverse cutting needle. Usage of cutting needles should be avoided because the sharp concave edge cuts through tissue during needle passage. This can lead to suture "pull-through" as well as increased hemorrhage.

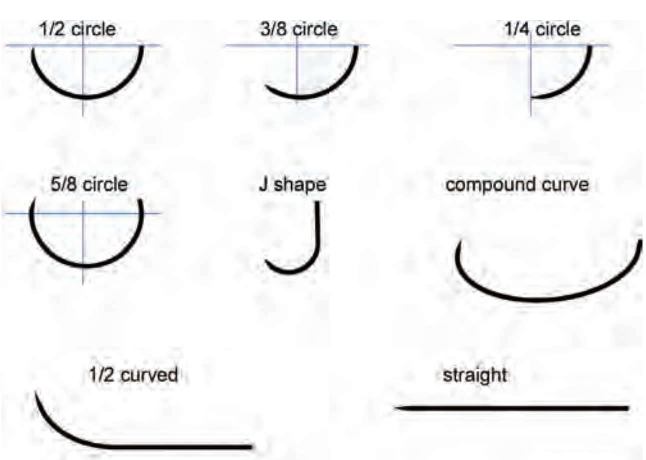

Figure 2-5 Numerous needle configurations can be used for intracorporeal suturing. In general, whereas shorter needle arcs allow easier needle retrieval, longer needle arcs facilitate working where access is limited.

Suture needles used in MIS should be strong enough to resist the increased forces placed on them during intracorporeal suturing. Suture needles are made of stainless steel alloys containing chromium and nickel. Chromium confers corrosion resistance, and nickel imparts strength to the needle. With the optimal component ratios, suture needles demonstrate the ability to deform without fracture, a property known as ductility.[6] Major suture manufacturers commonly produce standard and premium grade suture needles as part of their suture line. There is a premium to be paid for higher quality suture needles, which can be custom manufactured in combination with any suture material. Proprietary coatings are applied to suture needles to facilitate their tissue passage.

Barbed Suture

Two of the most difficult aspects of intracorporeal suturing are square knot formation and maintaining suture tension during continuous pattern suturing. The incorporation of barbed suture technology into MIS has made a significant impact in alleviating these difficulties.

In 2007, absorbable and nonabsorbable bidirectional barbed sutures (Quill SRS; Angiotech Pharmaceuticals, Vancouver, British Columbia, Canada) received U.S. Food and Drug Administration (FDA) clearance for use in approximating soft tissues.[7] These materials were cut from poliglecaprone and polydioxanone for absorbable sutures and polypropylene and nylon for nonabsorbable sutures. Quill SRS sutures feature a helically barbed strand with bidirectional barbs (10 barbs/cm) emanating from a central unbarbed segment. The strand itself is double armed and is meant to be applied so that the suturing process commences at the midpoint of the surgical incision. Suturing proceeds with each arm proceeding 180 degrees away from the center toward the opposite edges of the incision. At the end of the incision, the respective suture needles are directed 90 degrees laterally to the sutured line and cut flush with the tissue. With Quill sutures, the suture size naming convention is such that the size of the suture is a function of the parent strand from which it was barbed. For example, a 3/0 Quill suture is derived from a 3/0 parent strand. However, the strength of this suture more closely approximates a 4/0 USP suture.[8] This is important for the surgeon to bear in mind when using these products.

In 2009, absorbable unidirectional barbed sutures (V-Loc 90/180, Covidien, Mansfield, MA) were FDA approved for soft tissue approximation. These materials were produced from absorbable glycolide–dioxanone–trimethylene carbonate polyester (V-Loc 90) and absorbable polyglyconate (V-Loc 180). More recently, a nonabsorbable polybutester (V-Loc PBT) has become available. V-Loc sutures feature a single-armed strand with

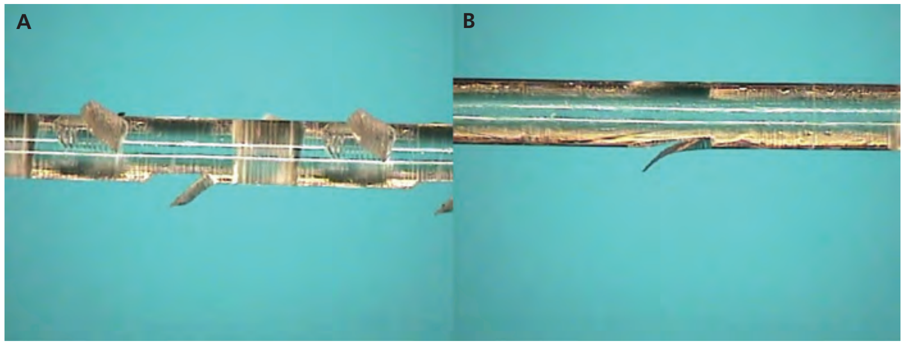

Figure 2-6 V-Loc 90 (**A**) and Quill Monoderm (**B**) barbed suture materials. V-Loc 180 sutures feature unidirectional dual-angle barbs with a suture needle on one end and a terminal welded loop on the other. Quill Monoderm sutures are double armed and feature bidirectional, helical, single-angle barbs that emanate from the center of the strand. (Reproduced with permission from J. Zaruby.)

unidirectional helical barbs (20 barbs/cm) that proceed from the swage toward the terminal end of the strand, which is welded into a loop. V-Loc suturing begins with advancement of the suture needle through the tissue on one side of the incision until the base of the terminal loop is reached. The suture needle is then passed through the tissue on the opposite side of the incision, leaving the terminal loop on the contralateral side. Before taking a third tissue bite, the suture needle tip is advanced through the terminal loop. The following suture bites may be performed in either a vertical or horizontal pattern to affect a simple continuous or mattress closure respectively. The suture size naming convention used with V-Loc sutures is such that the suture size is a function of USP tensile strength.[8] As such, 3/0 V-Loc suture has a tensile strength that is close to that of a conventional monofilament 3/0 suture. This eliminates the "mental gymnastics" that the surgeon might encounter when deciding an appropriate suture size for the tissue application. V-Loc sutures are available in sizes 0 to 4/0 and in 6-, 9-, 12-, 18-, and 24-inch strand lengths (Figure 2-6).

Barbed sutures can greatly simplify intracorporeal suturing. A notable example is in laparoscopic gastropexy. Maintaining suture tension during stomach suspension is greatly facilitated with barbed sutures.[9] Another example is in intrapelvic herniorrhaphy, in which suture approximation is difficult because of space limitations.[10] Other uses for barbed suture remain to be determined but are developing with MIS implementation in veterinary surgery.

Intracorporeal Suturing Technique

Please note that most descriptions in this section refer to right-handed surgeons, preparing to take a right to left suture bite, for the purpose of increased readability. The instruments involved usually consist of a needle driver in the dominant hand (right in the examples here) and either a good-quality grasper or a second needle driver in the nondominant (left) hand.

Cannula Placement

A fundamental difference between laparoscopic and open suturing is the restricted instrument mobility. The surgeon is confined by the cannula placement to a single arc of rotation perpendicular to the axis of the instrument. The cannula placement has to be as ideal as possible to make suturing easier. An intercannula distance of at least 5 cm is desirable for the needle driver and accessory instrument. The working tips of these instruments should meet at oblique angles with each other at a relatively wide angle of 60 degrees or more. If possible, the cannula for the right needle driver should be parallel to the suture line. The distance between cannula entrance and operative field should be approximately half of the length of the instrument (e.g., for 30-cm instruments, the cannula should be placed 15 cm [~6 in] from the target field).[2] The instruments and camera need to be directed in the same axis as the surgeon's view toward the screen to avoid mirrored vision.

Needle Introduction

The needle introduction method used depends on the type and size of needle, the size of the cannulas used, and the animal's size in relation to needle size. If the body wall thickness and needle size allow, the needle can simply be passed transcutaneously into the abdominal cavity anywhere in the surgically prepared area and be grasped intracorporeally with the needle driver. If so, the needle is ideally passed perpendicular to the dominant hand instrument axis so the needle can simply be grasped at the midpoint, and suturing ensues.

Often the needle and suture need to be passed through the cannula or the cannula site. If the needle size is compatible with cannula size, which usually requires a 10- to 12-mm cannula, the easiest introduction for a right-handed surgeon is to grasp the suture 2 to 3 cm from the swaged on end of the needle with the left instrument and pass it through the cannula. The suture is grasped with the needle tip pointing toward the left (Figure 2-7) and thus is ready to be grasped with the right hand instrument. If the needle position is not good, it can easily be corrected by applying gentle traction to the suture material (Figure 2-8). An alternative is to backload the needle and introduce through the cannula, and when intracorporeal, reposition the needle as described in detail later (Figures 2-9 and 2-10).[11] The cannula valve may need to be released when introducing to avoid disrupting the needle position or damaging the valve.

If the needle size is larger than the cannula allows, it may have to be passed through the cannula site with the cannula temporarily removed. The cannula is removed from the site while the assistant blocks gas exit, usually by placing a finger in the defect. The instrument is placed through the cannula, and when it is exiting through the cannula end, the needle is either backloaded or the suture is grasped 2 cm from the swaged end and introduced into the abdomen through the cannula site. The cannula through which the instrument is positioned is then immediately replaced in the site to minimize gas leakage.

Needle Positioning

For surgeons experienced in traditional open suturing, the challenge of obtaining correct needle positioning in the needle driver often becomes a surprise. In fact, it has been shown that for novice laparoscopic surgeons, needle grasping and positioning within the

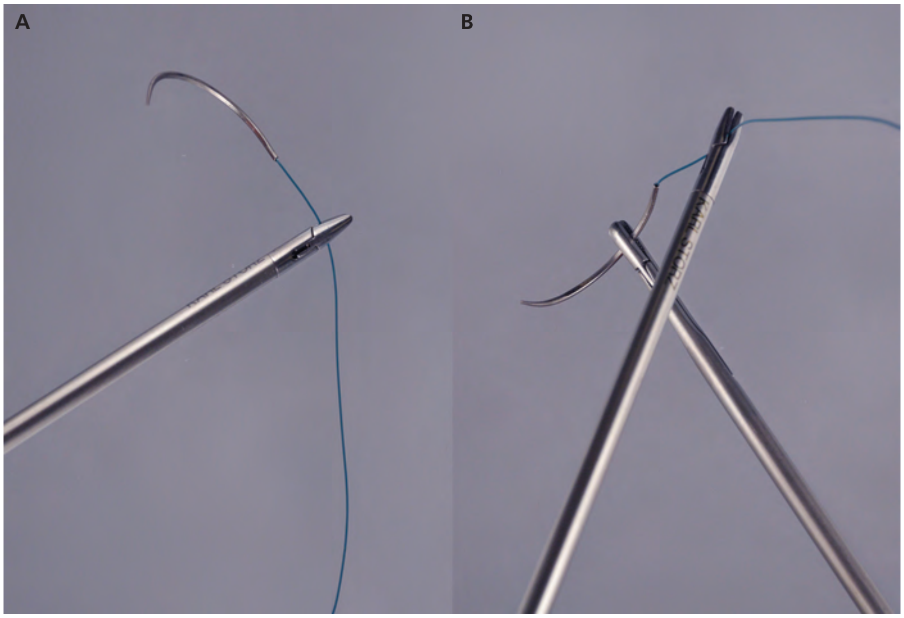

Figure 2-7 Needle introduction through a cannula. **A.** The suture is grasped with the left-hand instrument (for the right-handed surgeon) 2 to 3 cm from the swaged on end. The needle is then passed through the cannula. The cannula valve may need to be released when introducing to avoid disrupting the needle position. **B.** When visible in the field, the right needle driver is grasping the needle. The left instrument is maintaining grasp on the suture until needle position is as desired for the suture bite.

needle driver are the most difficult and time-consuming laparoscopic tasks.[4]

In our experience, the limitation of the two-dimensional view in determining if an acceptable perpendicular position has been obtained is one of the major challenges. Novices often do not understand the magnitude of the needle displacement until suturing is attempted and found to be near impossible. Self-righting needle drivers may be an important aid, but we have found that most trainees will learn the cues for needle positioning reasonably fast. If using a standard 3/8 circle needle, one cue to correct perpendicular needle positioning is that the light source is reflected along the side of the needle.

In the Veterinary Applied Laparoscopic Training (VALT) curriculum, we practice two varieties of needle positioning, the needle "dance" and a backloading technique described by Brody and coworkers.[11]

With either of the two techniques, if grasping the needle has resulted in a nonperpendicular position, the displacement is most easily corrected by unlocking the ratchet of the needle driver, and while still stabilizing and not letting go of the needle, using the ancillary instrument to grasp the suture 1 or 2 cm from the swaged on end of the needle and by manipulating the suture until a more perpendicular needle position is obtained (Figure 2-8, Video Clip 2-1).

When a perpendicular or near-perpendicular needle position has been achieved, the suture bite is performed very similar to open surgery. Clockwise rotation of the instrument handle will allow tissue purchase within the arc of the needle.

Needle Dance

The "needle dance" is commonly used when a left instrument has inserted the needle by grasping the suture. As the needle is visualized in the field, the convex part of the needle is allowed to lightly touch an organ surface, and the grasping instrument is "dancing the needle" by letting it pivot around the organ contact point until a position is reached where the needle driver can grasp the needle in a perpendicular position and be ready for a suture bite (Figure 2-11, Video Clip 2-2). Doing the "dance" midair is seldom successful; the surface contact is usually needed to manipulate the needle. If no suitable surface is available in the clinical situation, the alternative needle positioning method is called for.

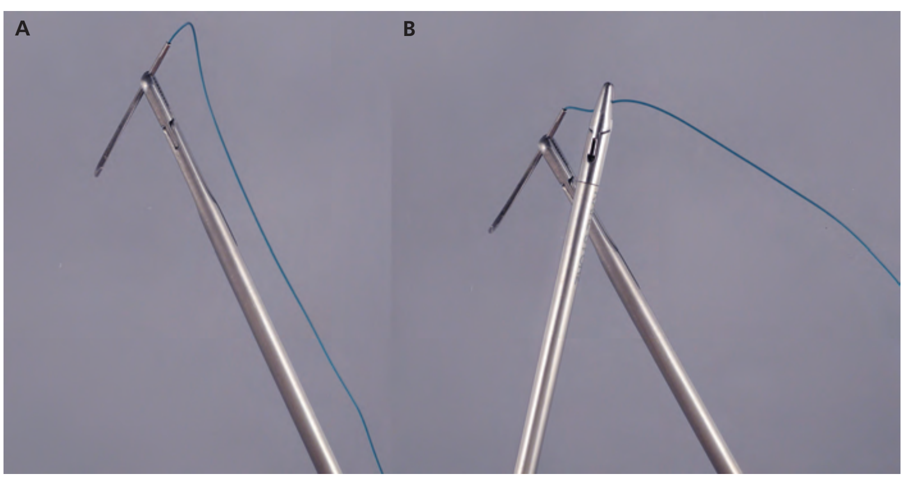

Figure 2-8 Needle position correction. **A.** The needle is not perpendicular in the jaw of the needle driver. **B.** The left-hand instrument grasps the suture, and the right hand is releasing the ratchet to loosen up the grasp of the needle without letting go of it. Now the suture can be gently manipulated until the needle is in a more optimal position.

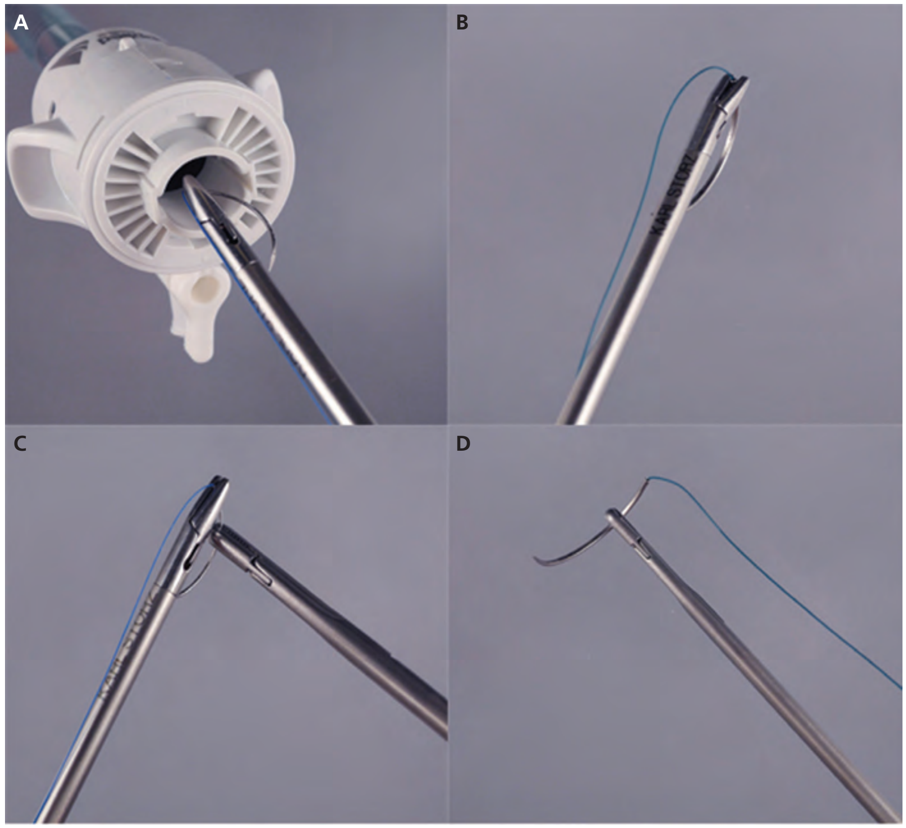

Figure 2-9 Needle introduction through a left-sided cannula according to Brody et al.[11] **A.** The needle is grasped with the left hand instrument backloaded (i.e., with the needle tip pointing in toward the shaft of the instrument). The convex part of the needle is positioned at 3 o'clock. **B.** The instrument is rotated clockwise 90 degrees so the convexity points toward 6 o'clock. **C.** The right needle driver can grasp the needle, one third to half the distance from the swaged on end, and the place the suture bite. **D.** The needle is well positioned for a right-to-left suture bite.

Brady Needle Introduction

The needle can be introduced backloaded on the left instrument,[11] with convexity to the right (Figure 2-9, Video Clip 2-1). If the angle between the instruments is less than 90 degrees, the left instrument needs to sway toward the lower right part of the visual field to allow a perpendicular grasping.

If the introducing cannula is located on the right, a backload technique can also be used (Figure 2-10, Video Clip 2-3).[11] This technique preferably is used with a needle driver in the right hand and a grasping forceps in the left, as the grasping forceps rotate around the instrument axis, making the 180-degree turn more ergonomic.

Techniques for Knot Tying: Simple Interrupted Sutures

Similar to open surgery, many knot-tying techniques are available in laparoscopic suturing. Here we will provide detailed instructions for two alternative techniques used in the VALT curriculum to successfully train a great number of novices.

After obtaining an appropriate needle position as described earlier, the ratchet is engaged with a firm grasp of the needle as the bite is initiated.

Knot Tying Using a Vertical Plane: The "Rosser Technique"

(Figure 2-12, Video Clip 2-4)

With this method, the right-hand instrument (needle driver) is always creating the throws around the left-hand instrument. When maximal driving along the arc of the needle has occurred, the right-hand needle driver is used to grasp the tip of the needle to disengage it from the tissue.

If a short (8–15 cm) suture is used, for interrupted suturing, our preference is to maintain this grip on the needle throughout the entire creation of the knot. Grasping the needle helps to control the suture memory to aid in the throws. If the suture is longer, the right needle driver has to release the needle and grasp the suture material closer to the incision during tightening of the knot and then regrasp the needle for creation of the next throw. It is important to realize that intracorporeally tied knots have a tendency to be less tight than knots tied under direct vision,[12] and it is necessary for the surgeon to counteract this tendency by ensuring that appropriate tension is applied.

Both instruments are located in the vertical plane above the suture site. A common novice mistake is to move the instrument tips from the suture site closer toward the surgeon, which will make knot tying harder.

For braided suture, the knot is complete with these three throws. However, for monofilament suture, two or three more single throws are required for knot security.

Paying attention to in which direction one is wrapping the suture material around the instrument needs to become second nature. Alternating between clockwise and counterclockwise wrappings (Figure 2-13) ensures that square knots are formed.

Knot Tying with Horizontal C-Loops as Described by Szabo *et al.*[13,14] (Figure 2-14, Video Clip 2-5)

If vertical space is limited, the instruments can work in a horizontal plane as described later (Figure 2-14). This technique also differs from the earlier one in that the throws are wrapped around the ipsilateral instrument (i.e., the throws are alternately made around the

Figure 2-10 Needle introduction through a right-sided cannula according to Brody et al.[11] **A.** The needle is backloaded on the right hand instrument (i.e., with the needle tip pointing in toward the shaft of the instrument) and introduced with the convexity to the left at 9 o'clock. **B.** Needle visible in the field at the 9 o'clock position. **C.** The right instrument is rotated clockwise 90 degrees so the needle convexity now points to 12 o'clock. **D.** The left instrument is grasping the needle. **E.** The left instrument has grasped the needle with the convexity still 12 o'clock. **F.** The left instrument is rotated counterclockwise 180 degrees so the convexity points to 6 o'clock. This technique preferably is used with a needle driver in the right hand and a grasping forceps in the left, as the grasping forceps rotate around the instrument axis, making the 180-degree turn more ergonomic. **G.** The needle can now be grasped at the appropriate position. **H.** The needle is positioned for a right-to-left suture bite.