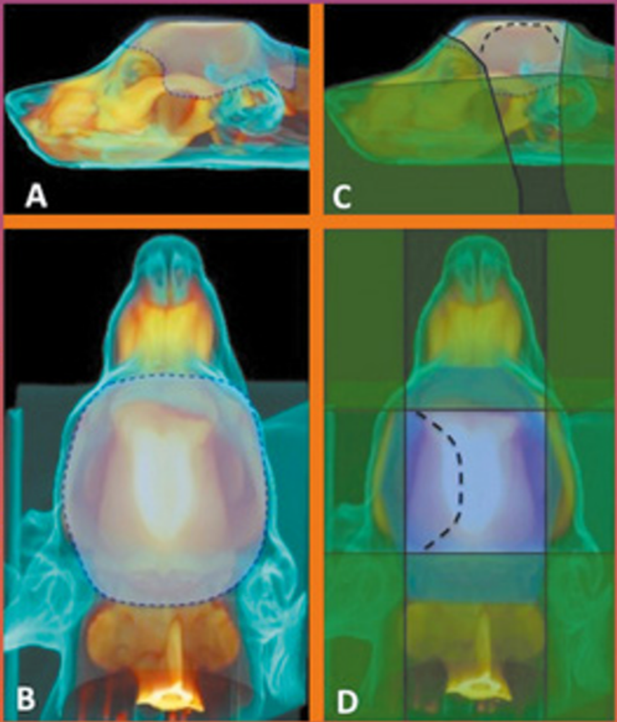
Current Techniques in Canine and Feline Neurosurgery

Edited by Andy Shores and Brigitte A. Brisson



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Current Techniques in Canine and Feline Neurosurgery

To my many mentors who shaped the direction of my career and planted many seeds that every day yield the fruits of their tutelage: Drs. Frank Hoerlein, Charlie Knecht, Steve Swaim, John Oliver, Ralph Henderson, Jimmy Milton, Bill Carney, Dick Redding, Don Sorjonen, Steve Simpson, and Paul Cechner – your teachings shaped me and continue to inspire me every day.

To all the surgery and neurosurgery residents I have had the pleasure of teaching and mentoring – passing the flames of this exciting profession and knowing your talents will be the new and exciting blossoms of the future of veterinary neurosurgery.

To *all* my family – my parents that afforded me every opportunity to pursue my profession; to my children, for all the smiles you've given me, for keeping me young, and for keeping me on my toes; to my grandchildren that show me there is hope for the future; and to my wife Jessy, gracias por todo, mi amor.

Andy Shores

To my husband Sean, for his incredible patience and unwavering support, which allow me to do what I love and to reach my dreams. You are my rock.

To my wonderfully inspiring and beautiful daughter Julia who brings so much joy, laughter and balance to my life. You never cease to amaze me. You are my world.

To the residents, interns and veterinary students I have had the privilege to teach and learn from. You motivate me to push further every day and remind me that there is always something new and exciting to learn.

To Dr. David Holmberg who was an incredibly talented surgeon and a wonderful mentor and colleague. Thank you for teaching me so much about neurosurgery and inspiring me to seek the answers to what I don't yet know. You are greatly missed.

Brigitte A. Brisson

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ACVS Foreword

The American College of Veterinary Surgeons Foundation is excited to present *Current Techniques in Canine and Feline Neurosurgery.* The ACVS Foundation is an independently charted philanthropic organization devoted to advancing the charitable, educational, and scientific goals of the American College of Veterinary Surgeons. 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.

Current Techniques in Canine and Feline Neurosurgery is edited by Drs. Andy Shores and Brigitte Brisson. Both are well recognized as experts in this field. They have chosen strong contributing authors to detail the areas of diagnostics and planning, intracranial and spinal surgery, and postoperative care and rehabilitation. We are sure you will find this reference extremely valuable.

The ACVS Foundation is proud to partner with Wiley Blackwell and the American College of Veterinary Medicine, and is honored to present this book.

R. Randy Basinger
Chair, Board of Trustees
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The American College of Veterinary Internal Medicine (ACVIM) advances knowledge of animal health and diseases, and fosters the continued development of specialty veterinary care in large animal internal medicine, small animal internal medicine, cardiology, neurology, and medical oncology. To achieve these purposes, the ACVIM certifies new Diplomates by guiding training programs, and ensuring fair and appropriate credentialing and examination procedures; promotes and advocates veterinary specialization; promotes continuing education and the dissemination of knowledge in veterinary cardiology, large animal internal medicine, small animal internal medicine, neurology, and oncology; and promotes the generation of new knowledge relevant to ACVIM specialties for the benefit of improved animal and human health.

Drs. Andy Shores (an ACVIM (Neurology) Diplomate) and Brigitte Brisson (an ACVS Diplomate) have collaborated on this issue to create a text which provides expertise from members of both veterinary specialty colleges. The ACVIM is proud to partner with the ACVS Foundation and with Wiley Blackwell to present this book.

Charles Vite
President, Neurology Specialty
American College of Veterinary Internal Medicine

About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/shores/neurosurgery

The website features the following video clips:

Video 5.1	A cerebrospinal fluid (CSF) tap performed on a dog in lateral recumbency, using a 22G, 1-1/2 inch spinal needle.
Video 10.1	The transfrontal craniotomy approach is demonstrated in this video, using a sagittal to remove a diamond shaped section of the frontal bone over the frontal sinus (video courtesy of Dr. Ane Uriarte).
Video 12.1	A suboccipital craniectomy is performed in a patient with Chiari malformation.
Video 13.1	A cotton tip applicator is used to free the bone segment from the dura for removal of the tumor and surrounding normal bone en-bloc.
Video 13.2	Rotational view of a preoperative 3D CT reconstruction of a dog with cranial tumour. The image can be manipulated in multiple planes to assist in preoperative visualization and planning.
Video 15.1	A modified right parasagittal ventral surgical approach and placement of transarticular screws for the surgical management of atlantoaxial subluxation in the canine are demonstrated (video courtesy of Dr. Fred Wininger).
Video 20.1	**Part I** The dorsolateral approach to the thoracolumbar spine is demonstrated in this video. In Part I, rongeurs are used to create a left-sided hemilaminectomy at L1-L2 on a small canine patient. In **Part II**, a nitrogen powered burr drill is used to create the hemilaminectomy at L1-L2 in a larger canine patient.
Video 21.1	Pediculectomy performed at T13-L1 through a dorsolateral approach on the left side (entire procedure).
Video 21.2	Modified dorsolateral surgical approach for pediculectomy.
Video 21.3	Following the initial approach through a dorsolateral incision, the spinal musculature is elevated using a periosteal elevator to identify the appropriate site for pediculectomy at T13-L1 on the left.
Video 21.4	An air drill is used to create a pediculectomy for removal of herniated disc material from the spinal canal.
Video 21.5	After drilling through cortical, medullary and inner cortical bone, the spinal canal is entered by removing the remaining, thin inner periosteum using an iris spatula or 90 degree bent needle and #11 blade.
Video 21.6	Opening of the remaining thin inner periosteal bone and removal of herniated disc material and hemorrhage from the spinal canal using an iris spatula.
Video 21.7	Using a bent iris spatula to retrieve herniated disc material from the spinal canal. The spatula is manipulated from craniodorsal and dorsocaudal toward the mid section of the pediculectomy ventrally to avoid pushing disc away from the pediculectomy window.
Video 21.8	Surgical closure of the modified dorsolateral approach used for pediculectomy.
Video 22.1	Blade fenestration performed at T13-L1 on the left following a pediculectomy procedure.
Video 24.1	Surgery is performed on a young, paralyzed canine patient with a gun projectile lodged in the dorsal aspect of the spinal canal at the T12-T13 junction. A modified dorsal laminectomy is performed at that site to both remove the projectile and decompress the spinal cord.
Video 29.1	Therapeutic exercises used in the rehabilitation of canine patients with neurologic diseases are demonstrated with commentary on the benefits of each exercise and the recommended number of repetitions for each procedure.

SECTION I

Diagnostics and Planning

1 Neurosurgical Instrumentation

Michelle Oblak and Brigitte A. Brisson

Introduction

The surgical suite should be large enough to accommodate the patient, anesthesia machine, and one to two instrument tables. Depending on the procedure performed, the surgeon may wish to have access to fluoroscopy to confirm the surgical site, anatomical landmarks, or implant position during the procedure. Specialized equipment may vary depending on the surgical approach and procedure to be performed. Preoperative imaging should be readily available for review. Spinal models are helpful, especially for the novice surgeon, to assist with anatomy and orientation as many surgical approaches have limited exposure. Surgical loupes or an operating microscope are useful for fine dissection around the spinal cord or brain; a nonsterile assistant helps set up these devices once the surgical approach is completed (Figure 1.1). Endoscopy may be utilized under certain circumstances and the use of an exoscope has become more commonplace in recent years (Figure 1.2).

Figure 1.1 Surgical loupes can be helpful in providing magnification of the surgical site.

Basic Surgical Instrumentation

A basic neurosurgical pack includes the following instruments:

- fine rat-tooth forceps (such as Adson tissue forceps);
- Debakey forceps;
- Metzenbaum scissors;
- Mayo scissors;
- scalpel handle(s) and blade(s);
- needle holders;
- sharp-blunt scissors to cut suture;
- small-tipped mosquito forceps (curved preferred);
- Frazier–Ferguson suction tip;
- a variety of fine neurosurgical curettes, spatulas, or dental tartar scrapers;
- rongeurs (Lempert, Kerrison or others);
- electrocoagulation (bipolar preferred).

Draping and Approach

Patients are positioned according to the procedure being performed. Draping involves the placement of four paper or cloth corner drapes secured to the patient's skin with towel clamps (Figure 1.3). A self-adherent impervious drape such as Opsite® or Ioban® can be placed over the exposed skin followed by a top sheet. Monopolar and bipolar electrosurgical instruments can be used to address hemorrhage that occurs during dissection (Figure 1.4). Only bipolar cautery should be used near the spinal cord or brain. Retraction of the skin and muscle is accomplished with a variety of different self-retaining retractors. Blunt retractors including Gossett and pediatric Balfours are helpful for a ventral cervical approach (Figure 1.5). Retractors equipped with multiple blunt or sharp teeth include Weitlaner, Adson-baby, and West retractors (Figure 1.6). These retractors can occasionally lead to damage to the surrounding neurovascular and soft tissue structures, so care must be taken when placing

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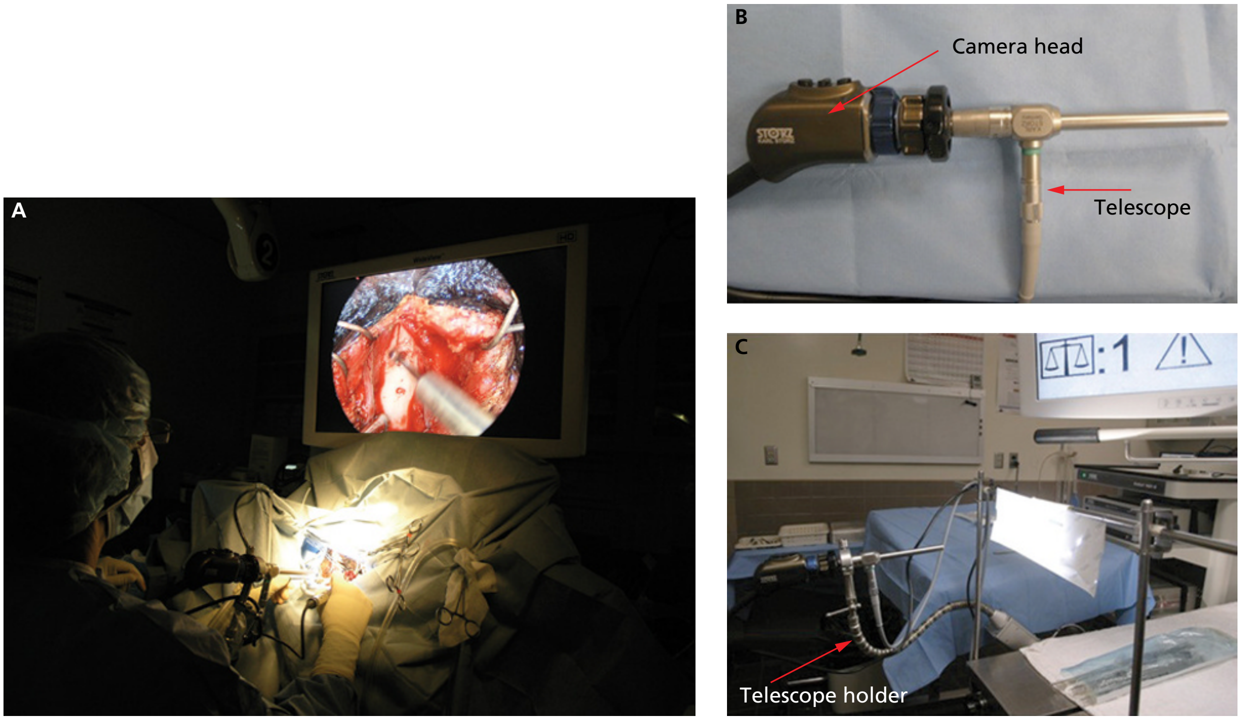

Figure 1.2 More recently, some surgeons prefer using an endoscope/exoscope for magnification during neurosurgical procedures: (A) intraoperative view of HD screen during surgery using an exoscope; endoscope and camera (B) and frame (C) used to stabilize the instrument during surgery. *Source*: Courtesy of Dr. Tina Owen, VCAWLA.

Figure 1.3 The patient is positioned and widely clipped for the surgical procedure. Following final preparation, an adhesive spray may be applied. Four half sheets are applied at the four quadrants of the surgical field and secured to the patient's skin with towel clamps. If used, an adhesive drape (such as Opsite® or Ioban®) is now applied followed by a top sheet (not yet applied in this picture).

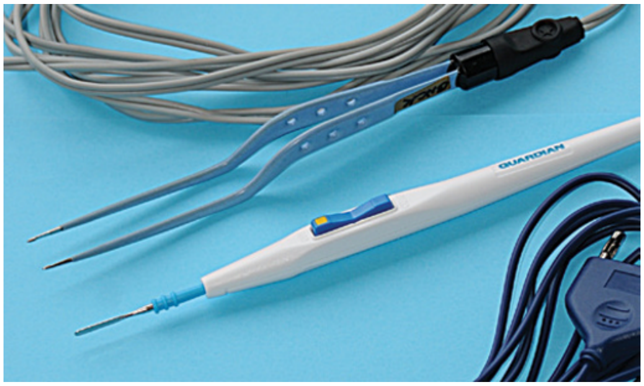

Figure 1.4 Electrosurgical instruments should be used sparingly around the spinal cord or brain. With bipolar cautery (*top*) the electric current passes between the tips of the forceps limiting lateral thermal injury compared with monopolar cautery (*bottom*) where the current passes from the instrument tip to the tissues and to the ground plate. Although bipolar cautery is the mainstay of electrocoagulation in neurosurgery, monopolar cautery is sometimes used for the initial approach when a more extensive approach is required (e.g., spinal fracture).

and removing these instruments. Like others, Gelpi retractors are available in a variety of angles and sizes. The 1-inch, 90°, medium-sized Gelpis are the authors' retractors of choice for dorsolateral approaches to the thoracolumbar spine of smaller dogs (Figure 1.7). These retractors have a sharp tip so caution must be exercised during placement and removal. Hand-held retractors, including Hohmann, Miller–Senn, Langenbeck, Army–Navy, and malleable, can also be used for exposure or to protect vital underlying structures but require an assistant (Figure 1.8). Elevation of soft tissues is performed with Freer or other periosteal elevators (Figure 1.9).

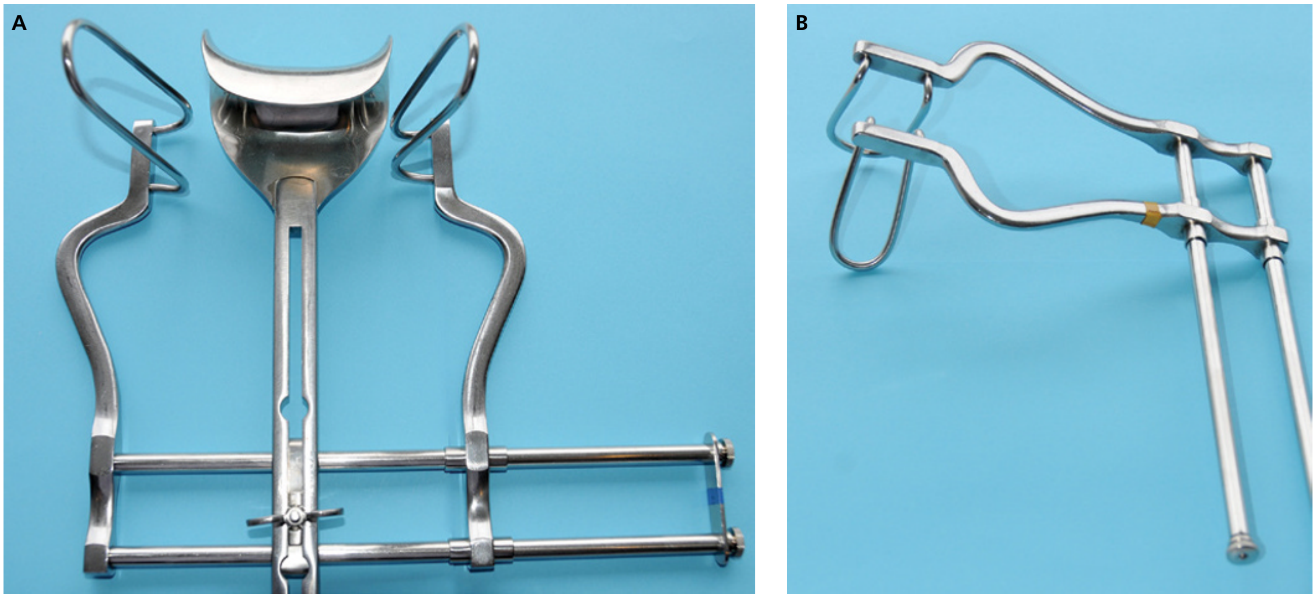

Figure 1.5 Blunt self-retaining retractors: (A) Gossett and (B) pediatric Balfour. Gossett or Balfour abdominal self-retaining retractors can be helpful for soft tissue retraction in a ventral approach to the cervical spine.

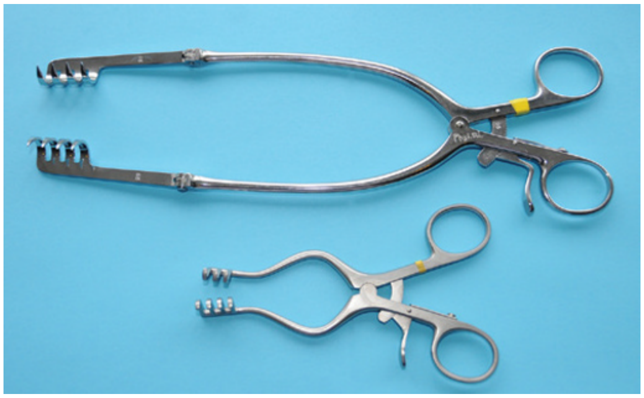

Figure 1.6 Toothed self-retaining retractors: Weitlaner (*top*) and Adson-baby (*bottom*). Weitlaner retractors are available in varying sizes. Weitlaner retractors have curved arms with varying numbers of curved (sharp or blunt) prongs on either end. A ratchet mechanism allows this instrument to remain in the spread position (with various degree of spread) after engaging the ratchet. Adson-baby retractors have a similar mechanism with varying tooth conformation.

Figure 1.7 The curved arms and sharp-angled tips of Gelpi retractors provide good leverage on tissues being retracted. A ratchet mechanism allows this instrument to remain in the spread position after retraction. They are frequently used for deep muscle retraction. The 90°, 1-inch medium Gelpis (*top*) are the authors' preferred retractors for spinal procedures in small to medium-sized patients.

Figure 1.8 Hand-held retractors: (*in sequence from top*) malleable, Hohmann, Langenbeck, Miller–Senn, and Army–Navy retractors. Hand-held retractors require an assistant for retraction but can be helpful in areas where more precise or varied retraction is necessary. The retractor chosen is based on the depth and fragility of tissues.

Figure 1.9 Freer elevator (*top*) and AO periosteal elevator (*bottom*). Elevators are used to elevate soft tissues from underlying bone.

Figure 1.10 An electric (not shown) or pneumatic (illustrated) drill is used to gain access to the spinal canal. Burrs of varying sizes are available and can be varied during the various stages of the drilling process.

Figure 1.11 3M Craniotome (unassembled handpiece). *Source*: Courtesy of Dr. Andy Shores.

Figure 1.12 CUSA ultrasonic tissue ablation system: assembled handpiece (A) and console (B). *Source*: Permission granted by Integra LifeSciences Corporation, Plainsboro, NJ, USA.

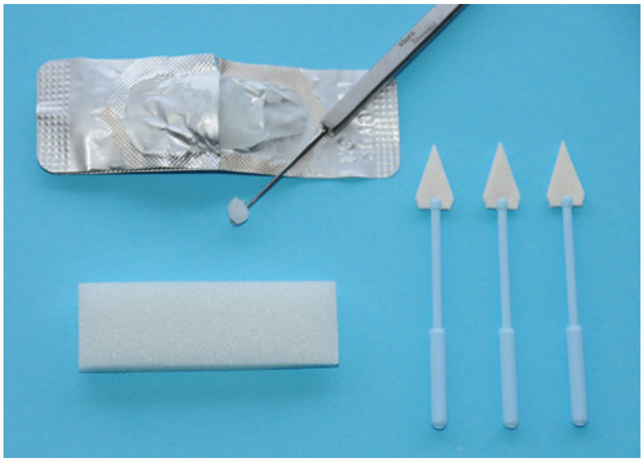

Figure 1.13 Hemostatics commonly used in neurosurgery: (*top*) bone wax; (*bottom left*) gelatin sponge; (*bottom right*) cellulose surgical spears.

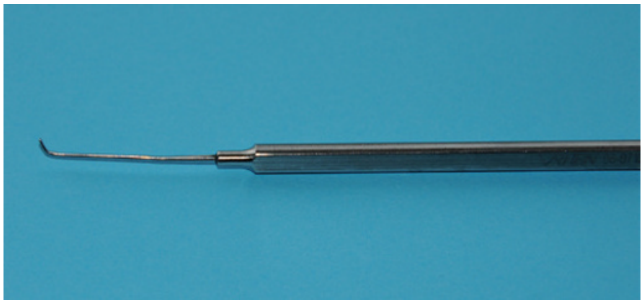

Figure 1.14 The iris spatula has a very fine tip that can be used for palpation and dissection and to retrieve disc material. Its tip is pliable, allowing the surgeon to bend it to a desired angle and length.

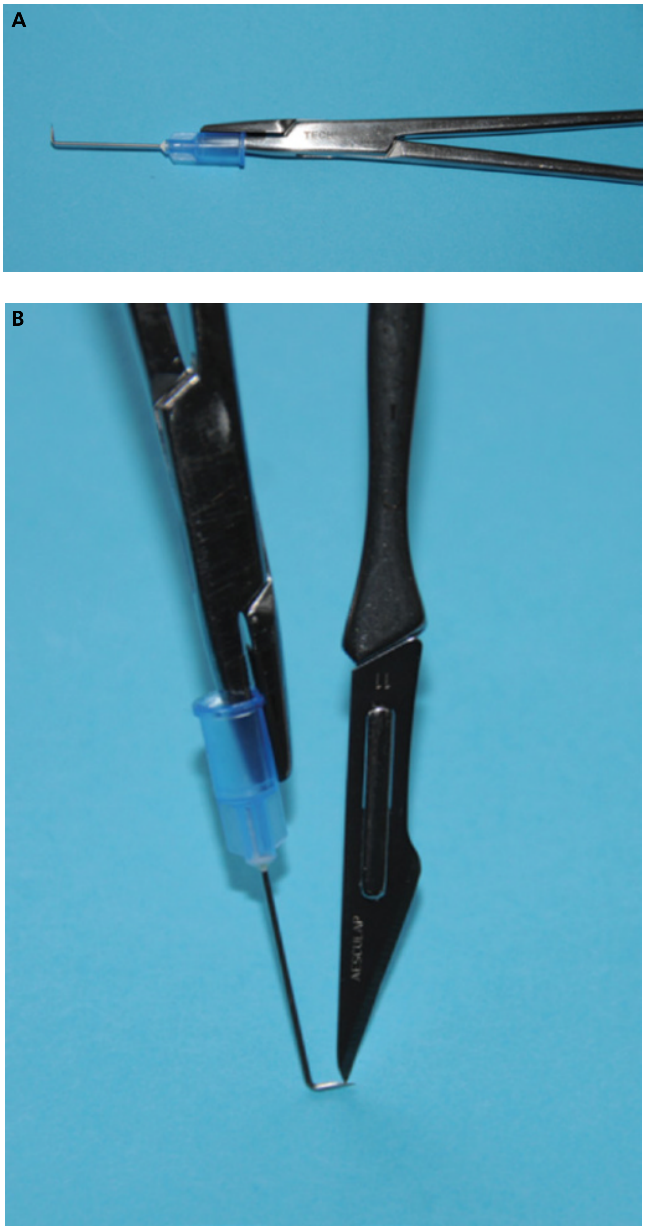

Figure 1.15 A 22G or 25G needle is bent at 90° (A) just caudal to the bevel (facing upward) and is used to penetrate and cut off the inner cortical bone/periosteum with the needle alone or with a #11 scalpel blade (B).

Access to the spinal canal is typically achieved using a pneumatic or electric drill. Burrs are available in a variety of configurations and sizes (Figure 1.10). Other specialized equipment used to penetrate the cranial bone or ablate tissues include the 3M craniotome (Figure 1.11) and CUSA (Figure 1.12). Intermittent or continuous saline irrigation should be available to remove bone dust created during burring and to decrease the heat transmitted to the bone and spinal cord. Bone wax is a sterile mixture of beeswax, paraffin, and isopropyl palmitate, a softening agent that can be used to control trabecular bone hemorrhage by acting as a mechanical (tamponade) sealant [1] (Figure 1.13). It is minimally resorbable and should be used sparingly as it can prevent bone healing, promote infection, and lead to granuloma formation [2]. As such, it should never be left in place in fusion sites and within the spinal canal and must never be used in contaminated fields [3].

Burring of the bone is continued to the level of the inner periosteum. Adequate cortical bone removal is typically confirmed by palpation with an iris spatula or other fine blunt-tipped probe (Figure 1.14). An effort is made to make an adequately sized window prior to removing the remaining thin periosteum and exposing the spinal cord. Once paper thin, the inner cortical bone/periosteum can be incised with a bent (90°) 22–25G hypodermic needle with or without the use of a #11 scalpel blade to enter the spinal canal (Figure 1.15). Once a full-thickness defect in the bone exists, it can be enlarged as needed using a burr, a Kerrison or Lempert rongeur, or a house curette (Figure 1.16). Kerrison rongeurs come in a variety of sizes and footplate thickness. Those with a low profile footplate are helpful for engaging the bony edge without damaging the spinal cord.

Retrieving disc material from the spinal canal is achieved with a variety of curettes, an iris spatula bent to the preferred angle and length, or with a dental tartar scraper (Figure 1.17). Appropriately sized brain spoons are used to mobilize brain tumors. Suction, using a Frazier–Ferguson suction tip, can facilitate the atraumatic removal of loose extruded disc fragments from the spinal canal or the removal of tumor tissue as well as hemorrhage from the surgical site (Figure 1.17). Cellulose surgical spears can be used to absorb mild hemorrhage and absorbable gelatin sponge can help control venous sinus hemorrhage

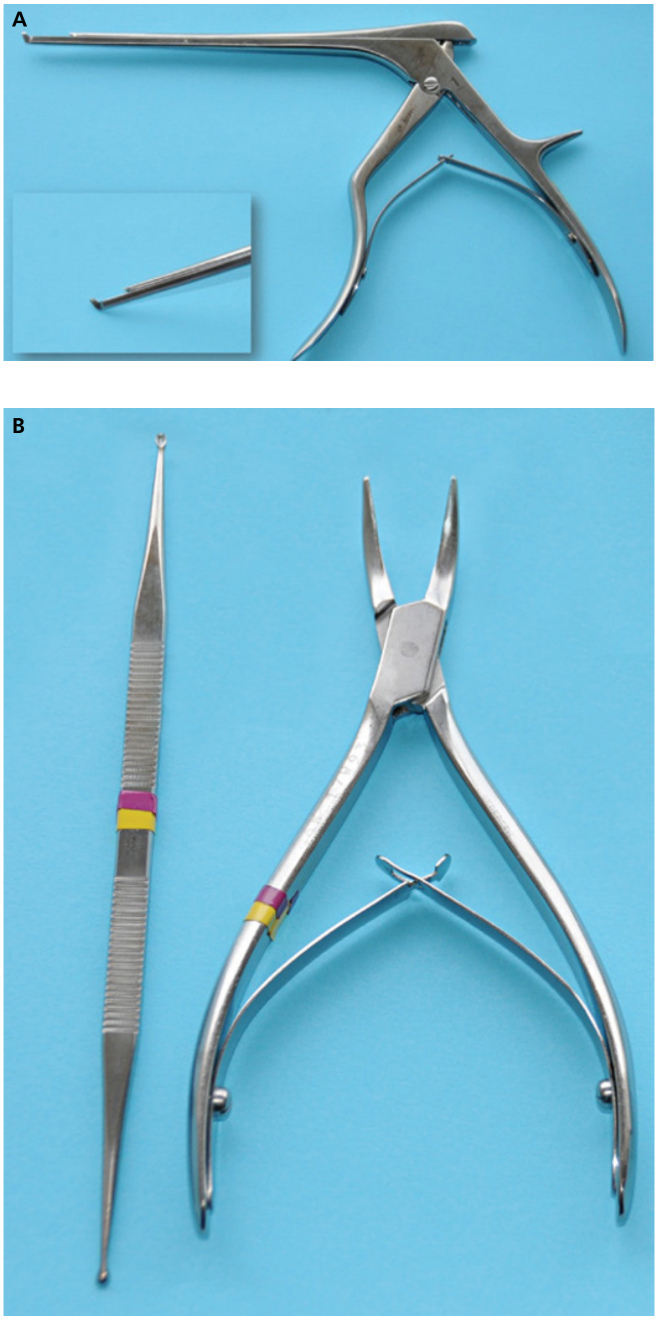

Figure 1.16 Kerrison rongeurs (**A**) have one long blade that ends as a footplate at the tip of the instrument while the other blade has a cutting end that meets the footplate when the instrument is closed. The footplate can be placed safely between the spinal cord and the bony lamina to allow atraumatic removal of small bony fragments at the edge of the laminectomy site. This instrument is especially useful in the cervical and lumbosacral areas because of the relatively greater space between the spinal cord/nerve roots and the bone. A house curette (**B**, *left*) is helpful for removing remaining endosteum when little space exists between the bone and spinal cord. Lempert rongeurs (**B**, *right*) with tapered jaws are used to grasp and remove smaller bone pieces along a laminectomy or craniotomy site.

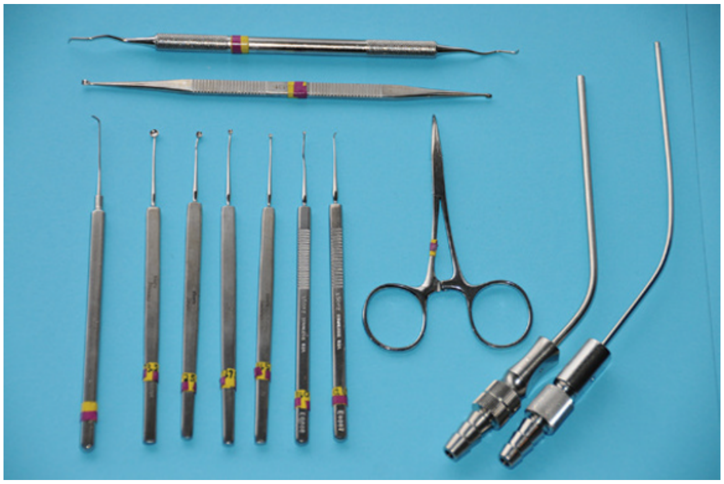

Figure 1.17 Retrieving disc material from the spinal canal is achieved with a variety of curettes, an iris spatula bent to the preferred angle and length, a dental tartar scraper, a small curved mosquito forceps, or with the use of suction through a Frazier–Ferguson suction tip.

Figure 1.18 A variety of fine-tipped scissors are used in neurosurgery to cut fine, delicate tissues. Iris scissors (*left*) have sharp tips and are available in varying sizes. Tenotomy scissors (*center*) are available as straight or curved instruments and also come in a variety of sizes. Potts scissors (*right*) have a sharp tip and are angled, typically at 45°. They are designed for vascular incisions where the bottom jaw is inserted within the lumen but can be useful for durotomy.

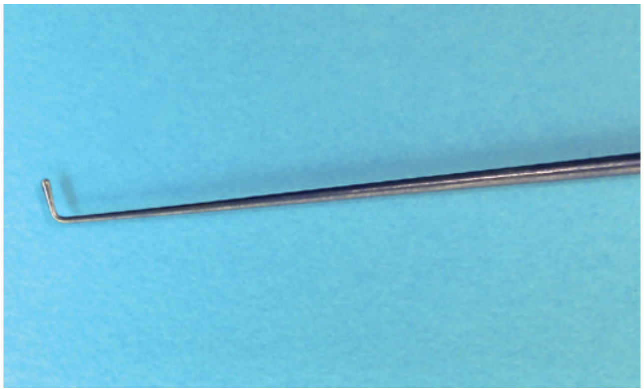

Figure 1.19 Nerve hook.

Figure 1.20 Lamina spreaders are equipped with small teeth at their tips and a ratchet mechanism that allows hands-free distraction of adjacent vertebrae. They are used for spinal distraction/stabilization procedures.

Figure 1.21 A variety of bone-holding forceps: clamshell (*top*), sharp-blunt (*bottom left*), Kern (*bottom center*), and sharp-sharp (*bottom right*). Bone-holding forceps can grasp the dorsal transverse processes or other portions of the bone during spinal distraction procedures or fracture repair.

Figure 1.22 Towel clamps are occasionally used to provide distraction during spinal distraction or fracture repair.

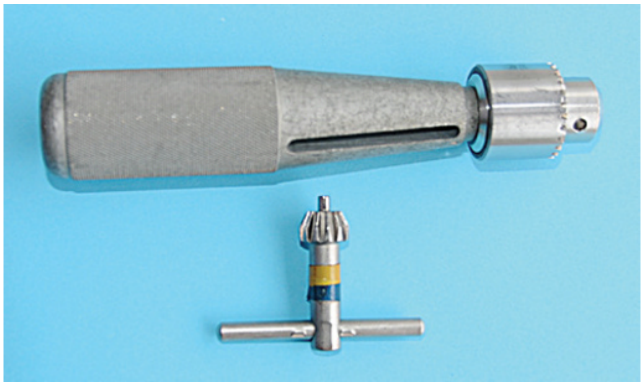

Figure 1.23 Hand-held chuck sometimes used to place implants such as pins into the spine.

Figure 1.24 Polymethylmethacrylate (PMMA) bone cement is frequently used for vertebral fracture stabilization.

(Figure 1.13). Gelatin sponge (Gelfoam® or Surgicel®) absorbs blood, swells and exerts pressure to produce hemostasis. It is resorbed over 4–6 weeks, but should be removed where possible as it may promote infection and granuloma formation, and in bone may slow or prevent healing [3]. Gelatin sponge has also been associated with temporary postoperative decline in neurological status in some patients [3–5]. Although granuloma formation has been reported when used in the brain [6], it is used frequently by veterinary neurosurgeons without such complication. A recent review of 60 veterinary cases where gelatin sponge was used at surgery found no associated complications but only four of these cases were neurological cases [7].

To access intradural lesions, the dura is incised using Potts, iris, or tenotomy scissors or a #11 scalpel blade. (Figure 1.18). Tenotomy and iris scissors are available in a variety of sizes and tenotomy scissors come as straight or curved instruments. Unlike iris scissors, tenotomy scissors have a blunt tip and are used for cutting fine, delicate tissues. Nerve hooks can be used for retraction of nerve roots (Figure 1.19).

Spinal stabilization procedures may be performed for atlantoaxial luxations, cervical spondylomyelopathy, lumbosacral disease, and spinal fractures. These procedures require the use of several types of implants in addition to the previously mentioned equipment. Laminectomy spreaders can be used to distract overriding vertebrae or fracture fragments (Figure 1.20). Sharp-blunt and Kern bone-holding forceps can also be employed to manually distract and reduce vertebral segments (Figure 1.21). Although not intended for this purpose, towel clamps are also sometimes used for this purpose (Figure 1.22). Implants are placed with pneumatic drills or manually with a hand-held chuck (Figure 1.23). A review of orthopedic implants and techniques for implantation can be found in Chapter 2.

Polymethylmethacrylate (PMMA) is a relatively inert, strong, lightweight bone cement that is often applied to stabilize implants around the vertebral column (Figure 1.24). Antibiotic impregnation is possible and may be recommended when the site is at high risk of infection. This product is available as a polymer and monomer that are mixed prior to use, resulting in a moldable cement that polymerizes and becomes hard through an exothermic reaction. Different consistencies of PMMA are available (liquid or dough) with the same end result; either can be used depending on surgeon preference and availability. Preventing excessive heat formation, especially close to the spinal cord, is paramount when using bone cement.

Video clips to accompany this book can be found on the companion website at:
www.wiley.com/go/shores/neurosurgery

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2 Orthopedic Implants in Neurosurgery

Noel M.M. Moens

Introduction

Surgical implants are routinely used in neurosurgery for the stabilization of unstable vertebral segments caused by fracture, luxation, or chronic degenerative processes and congenital malformations. Regardless of the implant being used, and for what purpose, the goals should be to achieve stable fixation and return the animal to full function in a consistent and reliable manner. This requires a basic understanding of biomechanics as well as a thorough understanding of how implants are loaded and how they should be used to ensure reliable results. This is particularly important since few implants used in neurosurgery were specifically designed for this purpose and rather were designed for fixation of long bone fractures.

This chapter is not designed to be exhaustive but to provide a quick overview of some of the different implants used in neurosurgery and to provide information on the rationale for their use and their limitations.

Pins and Wires

Surgical pins and wires are made of hardened surgical grade 316L stainless steel and come in a variety of sizes and designs. Small pins from 0.7 to 1.6 mm are often referred to as Kirschner wires or K-wires, while large-diameter pins, generally from 2 to 6 mm, are referred to as Steinmann pins. The pin or wire tips can have different configurations, with the most frequent being the trocar tip and the chisel tip (Figure 2.1). Other tip types exist but are not as common in veterinary medicine.

Figure 2.1 Steinmann pin tips with trocar (*left*) and chisel (*right*) tips.

The pins can either be smooth or threaded, with the threaded portion located at the end of the pin or in the middle section of the pin. Threaded pins can be either *negative profile* or *positive profile*. Negative-profile pins have the thread cut into the shaft of the pin, thereby decreasing the core diameter along the threaded portion of the pin. Although these pins provide better pull-out strength than smooth pins, their strength and bending stiffness are significantly decreased compared with smooth or positive-profile pins. Negative-profile pins are prone to breaking at the junction between the solid shaft and the threaded portion of the pin due to stress concentration at that level when loaded [1,2].

Positive-profile pins have their thread built over the pin core and have a uniform core shaft diameter along their entire length (Figure 2.2). They offer greater pull-out strength and better bending strength and stiffness than negative-profile pins. Positive-profile pins are manufactured with two different types of thread, one optimized for cortical bone, with smaller diameter and smaller pitch, the other optimized for cancellous bone with a larger thread diameter and longer pitch.

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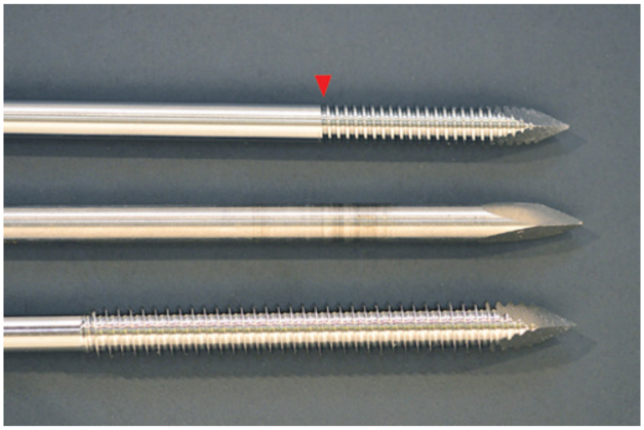

Figure 2.2 Negative-profile pin (*top*), smooth nonthreaded pin (*middle*), and positive-profile threaded pin (*bottom*). Note the decrease in core diameter of the negative-profile pin at the junction between the smooth shaft and the threaded portion (arrowhead).

Importance of the Pin–Bone Interface

In neurosurgery, pins are often used as internal fixators, where all the implants are contained under the skin: the pins are inserted into the vertebrae to provide purchase into the bone and are connected together, generally using acrylic cement (Figure 2.3).

In most cases, the pin–bone interface is the weakest link of the construct and the one aspect of the fixation that can be most easily compromised by poor surgical technique. No matter how strong the fixator, its efficacy ultimately relies on the integrity of the pin–bone interface and small, seemingly benign technical errors can easily and rapidly lead to the loss of the entire fixation. There are several ways to improve the pin–bone interface and influence long-term pin–bone stability [3].

Pin Insertion Technique

Bone is exceedingly sensitive to temperature increases, and thermal necrosis can be blamed for a significant number of fixator failures. A temperature slightly above 53 °C irreversibly damages bone and leads to necrosis, resorption, and loss of the pin–bone interface [4]. It is remarkably easy to exceed this temperature during drilling and pin insertion.

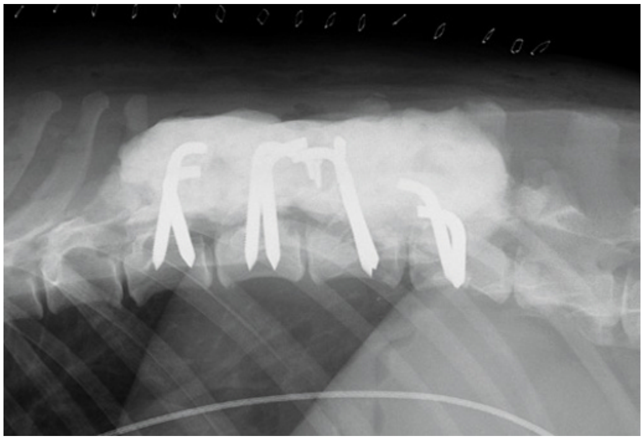

Figure 2.3 Spinal luxation in a dog stabilized using cortical positive-profile pins and PMMA cement. *Source*: Courtesy of Dr. Fiona James.

Low-speed power drill insertion (150 rpm) is the most recommended method of insertion and, if done appropriately, has been shown to keep bone temperatures within acceptable limits and is, for most applications, the preferred insertion technique [5]. Many surgical drills are designed for high-speed drilling and are therefore not ideal for pin insertion. Great care must be taken to avoid excessive speed during insertion as high-speed insertion almost invariably generates excessive heat and produces large areas of thermal necrosis of the pin track [4,5].

Manual insertion has been recommended to minimize the risk of thermal injury. However, manual insertion can also create wobble during insertion which can decrease holding strength. In a study on external fixation, smooth pins inserted manually with a hand chuck in canine tibiae demonstrated less holding power than a similar pin inserted at low speed (150 rpm) with a power drill [6]. The loss of pin purchase was blamed on the unavoidable wobble that occurs during hand insertion and the enlarged hole that ensues. The design of the pin tip also plays a role in the amount of heat that is produced during pin placement. The two most common pin types in veterinary medicine are the trocar and chisel tips. Although trocar tips are easy to manufacture and are the most common, they can generate a significant amount of heat by friction. Chisel tips are slightly more efficient and generate less heat than trocar tips but the difference has not been shown to be statistically different [7].

Predrilling

The benefit of predrilling a pilot hole into the bone prior to inserting the pin has been the topic of intense debate and remains controversial. Predrilling a hole close to, but slightly smaller than, the core diameter of the pin to be used into cortical bone has been shown to decrease the amount of microfractures produced during pin insertion and has resulted in an improved initial pull-out strength in canine tibiae [8]. However, differences in pull-out strength following predrilling were not observed in other studies [9,10]. In fact, a decrease in pull-out strength following predrilling has even been reported when predrilling was performed prior to screw insertion in bovine cancellous bone and in human vertebrae. As such, the recommendation was to drill only a short pilot hole into the vertebrae to allow the thread to engage. It is likely that the different and sometimes contradictory findings are the result of different testing methodologies, insertion sites, bone characteristics, and techniques. It appears safe to recommend predrilling with a drill bit slightly smaller than the core diameter of the pin when dense cortical bone is likely to be encountered but that predrilling vertebral bodies or cancellous bone beyond the creation of a short pilot hole may not be necessary.

Irrigation

Another method of effectively controlling temperature during insertion is to dissipate the heat produced using copious irrigation with cool sterile saline. This method has been shown to be effective at avoiding thermal necrosis in the bone [11]. It must be noted however that irrigation is much less effective on the pin tip once it has penetrated the first cortex (cis-cortex) and engages the second cortex (trans-cortex). An increase in temperature of up to 9 °C has been measured as the pin engages the far cortex [12]. As such, irrigation alone cannot replace good pin insertion technique.

Length of Bone Engagement

Holding power for screws in cancellous bone is dependent upon the diameter of the thread, characteristics of the thread design, the quality of the bone, and the length of engagement [13].

Because the resistance to pull-out is directly linked to the length of the pin engaging the cancellous bone, it is important to maximize this length. Ideally, the pin should penetrate the trans-cortex to ensure maximal bone engagement [14]; however, bicortical engagement is not always possible or advisable in neurosurgery due to the high risk of penetrating the spinal canal. The depth of penetration must be carefully controlled during insertion. Over-penetration must be avoided because it can cause irreversible damage to essential structures. Because of the thin cortices of vertebral bodies, it may be difficult to identify at which point the pin penetrates the cortical wall. Measuring the bone and the pin prior to insertion is therefore essential and will help reduce the risk of over-penetration. If a pilot hole has been drilled, the length of the hole can be measured using a depth gauge and the distance of penetration compared to the length of the threaded portion of the pin as a guide. Premeasurements from radiographs or CT images can also be very useful for determining acceptable penetration length. Backing out a pin that has been inserted too far should be avoided unless necessary, as the back and forth movement has been shown to decrease the pin–bone interface and holding strength [9].

Pin Thread Design

In long bone external fixation, the design of the pin thread appears to have a significant effect on the short- and long-term stability of fixators. Threaded pins have significantly greater initial pull-out strength than smooth pins. They are also less likely to loosen during the postoperative period. Threaded pins have been shown to have a 14-fold better pull-out strength than smooth pins 8 weeks following tibial implantation in the dog [1]. It is reasonable to assume that the same trend would be observed in vertebrae. The choice between cancellous and cortical threaded pins remains controversial and likely depends on bone characteristics, thickness, and quality. In theory, cancellous threaded pins have a larger thread diameter than cortical pins and will therefore better resist pull-out forces. They are, however, generally manufactured with a smaller core diameter than cortical pins in order to maximize thread depth, thus making them weaker in bending and shear. Because internal fixators are often loaded in bending and shear, the quest for larger thread should not come at the expense of the core diameter of the implant or failure is likely to be observed [15,16]. The pitch of a screw is the distance between two consecutive threads. Cancellous threads have a larger pitch than cortical threads in order to capture more bone between each thread. This theoretically increases pull-out strength if enough bone can be engaged, but it can result in poor holding strength if bone penetration is shallow or if the bone is thin since fewer threads actually engage the bone.

Importance of the Pin–Cement Interface

For many neurosurgical applications, pins or screws are secured using acrylic cement (polymethylmethacrylate, PMMA). Acrylic cement does not truly adhere to metal and the initial adhesion that may exist between the cement and the pins is generally short-lived. Long-term stability is provided by the creation of a more durable interlock between the cement and the implants [14,17,18]. This is particularly critical as contamination of the pin surface with blood or fat is almost unavoidable and further decreases cement adhesion. Notching the pins using a pin cutter creates grooves on the pin surface, allowing the cement to interlock with the pins and has been recommended to prevent pin loosening and migration [14]. Cutting the pin to length and bending the end of the pin may also be a good way to increase the interlock between the pin and the cement. Although it is very difficult and potentially dangerous to bend or even cut large pins in situ after implantation, it is possible to precut and to bend the pin prior to insertion. In this instance, the bent pin can be carefully inserted through a predrilled hole using a hand chuck. Care must be taken to avoid wobble that could cause deterioration of the pin–bone interface. Some small pins are specifically designed for composite fixators and their shaft surface is covered by a fine thread to improve cement interlock (Figure 2.4).

Figure 2.4 Imex Miniature Interface® pins (IMEX Veterinary Inc., Longview, TX, USA). These pins have a threaded tip and a roughened core to ensure a better grip of the acrylic cement. These are available in diameters from 0.9 to 2.4 mm.

Bone Screws

The development of new implants and new surgical techniques has been associated with a parallel evolution in bone screw design. The thin and fragile nature of the bone in maxillofacial surgery and neurosurgery has also contributed to new screw designs with better purchase in thin and poor-quality bone. The recent development of locking plate systems has also significantly changed the function of screws and their design.

In orthopedics, screws are generally used to secure bone plates to bones or provide interfragmentary compression, whereas in neurosurgery compression is rarely applied to the construct. Instead, screws are often used in combination with PMMA cement as an alternative to pins for the construction of internal fixators. Screws used in this fashion become part of an *angle-stable* construct and are subjected to different forces from traditional plate screws. This difference must be taken into account when selecting the size and type of screw for this particular use.

The main characteristics of a screw are its length, thread diameter, core diameter, and pitch. The thread diameter, also referred to as the major diameter, generally identifies the size of the screw and is the major determinant of the screw pull-out strength. The core diameter, also known as the minor diameter, is the diameter of the shaft and in most cases dictates the diameter of the hole that must be drilled into the bone before insertion. The core diameter is the main determinant of the shear strength and bending strength of the screw and has a lesser effect on the pull-out strength of the screw. The pitch is a characteristic of the thread and can be defined as the distance between two consecutive threads (Figure 2.5).

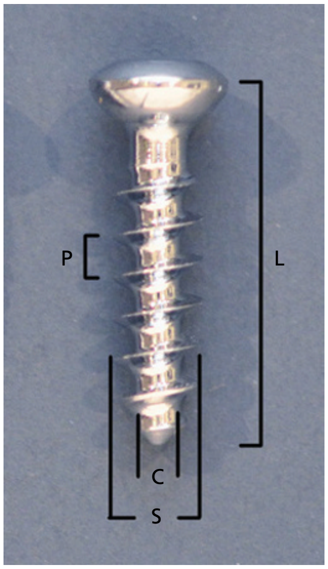

Figure 2.5 Characteristics of a bone screw. L, length of the screw. S, screw diameter, also known as major diameter or thread diameter; it is a major determinant of the pull-out strength of the screw. C, core diameter or minor diameter; the minor diameter is an important determinant of the bending and shear strength of the screw. P, pitch, the distance between two consecutive threads; in most screws with a single start-thread, it is also the distance that the screw will advance if turned 360°.

Figure 2.6 Tapping the hole with the appropriate tap is always done using a tap sleeve to minimize entrapment of the soft tissue but also to steady the tap and decrease wobble.

Screw Insertion Technique

Similarly to pins, the preservation of the bone–screw interface is essential for the long-term stability of the construct [19]. Many of the aspects of preservation of the pin–bone interface apply to bone screws and have been described earlier in this chapter. The basic sequence for bone screw insertion is drill, measure, tap, and insert.

Predrilling

Unlike pins, which have a sharp point, insertion of screws generally requires predrilling of the bone. The diameter of the hole is dictated by the core diameter of the screw. Because of the many sizes of screw available, a wide range of drill bit diameters and lengths are also available. It is essential to carefully match the drill bit to the core diameter of the screw as creating too small a hole will not allow screw insertion and creating too large a hole will automatically decrease the holding strength of the screw [19].

Drilling must be done with great care to avoid thermal necrosis of the bone and creating an unnecessarily large hole. Sharp drill bits and irrigation must be used to ensure the hole is drilled efficiently and with as little heat generation as possible. The use of a drill sleeve or drill guide during drilling is also essential to protect the soft tissues from catching, but also to minimize wobble and enlargement of the hole.

Measuring

Measurement of the length of the hole is generally performed after drilling but before tapping so as to not damage the delicate thread cut into the bone using a bone tap. This is often performed with a specialized depth gauge but can sometimes be achieved by using specifically designed graduated drill bits. Depth gauges are often graduated in 2-mm increments. For all bicortical screws, the measured length from the depth gauge is generally rounded up to the next measurement to ensure that the tip of the screw fully exits past the trans-cortex of the bone. If a monocortical screw is to be inserted, a screw slightly shorter than the measured distance is chosen to avoid contact with, or penetration of the trans-cortex. Because errors can easily occur when using the depth gauge, it is always recommended to double check the measurement against radiographic or CT measurements and to use common sense.

Tapping

Tapping is the creation of the thread in the bone using a specific instrument that exactly matches the characteristics of the chosen screw thread and cuts the thread into the bone as it is advanced. Tapping is a delicate operation that carries a high risk of damaging the hole and immediately reducing the screw's holding strength. As each type of screw has a specific thread pattern, one must choose the appropriate bone tap for the screw to be inserted. The orientation of the tap must exactly match the orientation of the drilled hole or stripping of the thread will occur. Wobble while tapping must be minimized as it enlarges the size of the hole or damages the thread. For this reason a tap guide of appropriate size is always used, even if surrounding soft tissues do not require protection (Figure 2.6).

Screw Insertion

Screw insertion must be carried out carefully in order to prevent damage to the previously created thread. The orientation of the screw must carefully match the orientation of the tapped hole or damage to the thread will occur. Over-tightening of the screw will result in stripping of the thread. Stripping of the thread during screw insertion may be the result of poor bone quality and bone mineral density, inappropriate hole preparation, or inappropriately high torque during insertion. Stripping of the thread immediately decreases the holding strength of that screw by more than 80% and presents a significant challenge to the surgeon [19]. Replacing a stripped screw by a slightly larger screw (also known as a rescue