Spinal injuries and associated neurologic dysfunction are encountered frequently in small animal practice. Such injuries are most often the result of automobile trauma, or less commonly gunshot injuries, falls from heights, or animal abuse. The vertebral column has two distinct functions that become compromised in the injured animal and that must be considered in the diagnosis and management of each case. The first function is to house and protect the spinal cord itself. The prognosis and treatment of spinal fractures and luxations are strongly dependent upon the degree of neurologic injury and thus its accurate assessment. The elements of a good neurologic examination relating sensory and motor deficits with the location and severity of the spinal cord lesion are discussed in Chapter 62. The classification and treatment of spinal cord injuries will be discussed briefly in the sections to follow.

The second important function of the vertebral column is the structural support offered as a part of the axial skeleton. The most effective treatment of the injured spine must be based on an understanding of the biomechanics of the spine in the normal and damaged states. This knowledge will allow the veterinary surgeon to better understand the forces involved in the etiology of the spinal injuries and to better understand the forces that must be overcome in spinal stabilization. This biomechanical foundation allows the most effective application of stabilization techniques and permits the creative surgeon to rationally improvise or develop new techniques where needed. This chapter will begin with a description of the basic biomechanical considerations of the spine and spinal injuries. The diagnosis, classification, and management of fractures and luxations of the spine will follow.
reduction and distribution along the spine. Although the detailed characterization of these forces in animals has not been made, their importance should not be underestimated or overlooked. This becomes particularly relevant in the manipulation of injured animals, in whom these protective intrinsic forces are reduced or absent owing to the loss of nervous control as a result of the traumatic event, surgical intervention, or anesthesia. Extrinsic forces arise from environmental influences and are thus more random in orientation and magnitude. They range from the bumps of walking into a door, the motion secondary to bandaging procedures, or the forces generated in the unfortunate animal hit by a car. Intrinsic or extrinsic loads that exceed the ultimate materials or structural strength of the spine result in catastrophic failure with displacement of the axial skeleton and damage to the sensitive neural tissue of the spinal cord. Both functions of the spine mentioned above-the protection of the spinal cord and support of the axial skeleton—are thus compromised.

The large bending, shear, or torsional forces acting on the spine will lead to failure at its "weakest point." The location of this point is dependent upon and varies with the materials properties of the tissues forming the spine, the local structural properties, the regional structural properties, and the type, magnitude, and orientation of the forces.

Two fundamental material components form each unit of the spinal column. These are the discrete bony segments (vertebrae) and the interposed soft tissue (ligaments, disks, joint capsules, cartilage). Ligamentous failure results in spinal luxations, which may occur without associated fractures. Similar forces acting on the immature spine may lead to failure at the physes owing to the relatively inferior strength of the cartilaginous components in this area. Feeny and Oliver,(17) in a retrospective radiographic study in dogs and cats, found that the vertebral body was the most commonly fractured portion of the vertebra, constituting approximately 50% of the cases of fracture/luxation. Interestingly, 20% of luxations occurred without any radiographic evidence of fracture. Concomitant disk prolapse at the fracture/luxation site or elsewhere occurred in 12% of the cases, while 17% of the fracture/luxations evidenced no radiographic narrowing of the neural canal.

The local structural properties also play a large role in the type of failure seen in spinal injuries. Injuries of the canine spine can be divided anatomically and biomechanically into three types: those involving the dorsal structural components, including the neural arch, associated processes, and ligaments; those involving the ventral structural components consisting of the vertebral bodies and disks; and those involving both dorsal and ventral components.(49)

The dorsal components are best suited to transmit tensile forces along the spine but have relatively little capacity to withstand compression. In contrast, the ventral components, exhibiting some of the mechanical components of long bones, are able to sustain the major compressive loads transmitted through the entire spine during weight bearing and propulsion. As a unit, then, the spine is best able to withstand the forces that result in bending in ventral flexion. This simultaneously loads the dorsal components in tension and the ventral components in compression. The structural design of the spine also allows a wide range of flexural mobility in other planes (e.g., lateral bending or extension) and in rotational (torsional) movement, but in these loading modes the ultimate strength properties of the spine are more limited. A mechanical disruption in both dorsal and ventral stabilizing components results in complete instability and allows both angular, rotational, and translational displacements. Translational displacements are most often associated with abrupt narrowing of the neural canal and profound cord compression.

The mechanical properties and therefore the type and frequency of injuries vary with the region of the spine in question. Feeny and Oliver, in the study mentioned above, evaluated the relative distribution and characteristics of various spinal injuries.(17) Spinal fractures/luxations in the dog occurred most frequently in the lumbar area (37.5%), followed by the sacrococcygeal (27.3%), thoracic (21.9%), and cervical regions (5.5%). Cats, in contrast, most commonly sustained fractures/luxations of the sacrococcygeal area (42.7%); the remaining distribution was essentially the same as for the dog.

The thoracolumbar and lumbosacral junctions are particularly prone to fractures and luxations because they are sites of marked transition between the stiff and mobile sections of the spine.(36,42,54,67,82) The mechanical properties of the spine, particularly bending stiffness (see section on biomechanics), change dramatically in these areas owing to the stabilizing effect (inertial properties) of the rib cage and pelvic girdle. The application of forces on the spine, particularly bending forces, results in stress concentrations at the thoracolumbar and lumbosacral junctions that, if sufficient in magnitude, will lead to failure by fracture or luxation. As mentioned, the spine is best suited structurally to withstand the forces that produce ventral flexion. Nevertheless the vast majority of fractures in these areas are the result of hyperflexion producing vertebral body failure.(43,82,110)

The final factor that determines the type of failure seen in clinical cases of spinal injuries is the magnitude and orientation of the combined intrinsic and extrinsic forces acting to produce the injury. Fractures and luxations of the spine can be
characterized by the mechanics of their etiology. A pure compression fracture of the vertebral body stemming from
compresive forces imposed on it from adjacent vertebral bodies results in shortening of the body but no significant
displacement. The resultant fracture line may be transverse directly through the vertebral body (compressive failure) or may
be oblique in any plane (shear failure). This vertebral body compression may be created either by pure axial loading of the
spine or by ventral flexion.

Pure tensile fractures of the spine occur less frequently owing to the nature of the animal trauma. One example of a tension
injury is the sacroccygeal fracture/luxation in dogs and cats resulting from the tail being caught or pulled with excessive
force. Tension also may be imposed on the cervical vertebrae when small dogs are picked up around the head and neck by
larger dogs and shaken. Bending (ventral flexion), which produces the vertebral body compression described above,
simultaneously causes the articular facets to be focally loaded in tension and may result in avulsion fractures of these bony
prominences. Selective rotational or compressive loading of the dorsal structural elements is likely to cause bony fracture or
ligamentous tearing depending on applied load orientation.

The nature, magnitude, and orientation of the traumatically inflicted forces acting to create injury are often complicated and
change rapidly over a short time. For this reason, the resultant injuries may actually represent structural or material failure in
any one or any combination of the modes described above.

THE BIOMECHANICS OF SPINAL STABILIZATION
The veterinary surgeon, in order to make a rational selection of internal fixation method, must understand the extent of
mechanical deficits and have a knowledge of the stability and strength provided by the fixation method relative to the specific
injury being treated. Unfortunately, such information is not readily available. Although many papers on the biomechanics of
spinal stabilization are beginning to appear in human medical literature, the veterinary literature to date consists mainly of clinical reports about the management of spinal injuries by application of surgical techniques that
have been empirically designed and tested. The results of comparative biomechanical testing of human cadaver spines subjected to various methods of internal fixation are in general not directly applicable to
veterinary surgery as it is practiced today. Most investigations focus on the use of compression or distraction instrumentation
e.g., Harrington rods) applied either to the lamina or to the transverse processes of the vertebrae two to three segments to
either side of the fracture/luxation instability. Although these techniques, when applied for the appropriate set of indications
in humans, yield superior spinal stability, the fixation systems are expensive and have not yet been reduced in size to fit
the wide size range of veterinary patients. Additionally, the dog and cat, compared with humans, have less well-developed
dorsal lamina and smaller neural canals in relation to the contained spinal cord, thus complicating adequate hook placement.
In spite of this, a few generalizations regarding spinal instability and the selection of implant fixation are apparent from these
investigations. Biomechanical evidence suggests that the loss of dorsal stabilizing structures with intact ventral elements is
best treated by the application of fixation dorsally. Dorsal fixation, applied to withstand tension, resists ventral flexion by
counteracting the tensile forces generated between adjacent dorsal lamina and dorsal spines. Compression and distraction
instrumentation, including spinal stapling, perform in this fashion but in addition manifest stability by the inherent materials
strength of the device to resist three-point bending. Realistically, selective dorsal vertebral instability is not commonly
recognized in veterinary practice. In addition, it would not likely require surgical treatment owing to the inherent stability of
the ventral components. Similarly, the selective absence of ventral stabilizing elements requires little or no fixation unless it
involves a vertebral body fracture that has no capacity to withstand axial compressive forces and will thus collapse or
override. In this instance, some form of internal fixation that will buttress the fracture site is indicated, such as vertebral body
plating. Fixation applied dorsally under these circumstances would be exposed to large bending forces and subject to
premature failure.

The selective loss of either dorsal or ventral structures separately results most typically in angular displacements of the spine.
Loss of both structural compartments simultaneously, however, as in complete fracture or luxation, introduces the potential
for translational displacements having the capacity to cause severe narrowing of the neural canal and cord compression.
Surgical stabilization for this type of complete injury is definitely indicated and may necessitate fixation of both dorsally on
the lamina or spines and ventrally on the vertebral bodies in addition to bone grafting to provide long-term stability.

The biomechanical evaluation and comparison of fixation techniques is currently becoming the focus of research endeavors
in veterinary medicine today. The results of these studies, if evaluated critically and carefully, should provide valuable
information about the choice and application of internal fixation techniques to the canine spine.
MANAGEMENT OF SPINAL INJURIES

Treatment of fractures and luxations of the spine is determined by the location and severity of the spinal cord damage and by the nature of the spinal structural damage. The elapsed time since the traumatic episode, and the informed decisions of the owner must also be considered. The management, in general, can be divided, as shown in the flow diagram (Fig. 19-1) into initial treatment, diagnosis, and surgical-nonsurgical management.

INITIAL TREATMENT

Initial treatment consists of assessing and prioritizing the patient's problems relative to their life-threatening potential. Clearly, the animal's cardiovascular and pulmonary status must be stable before moving on to evaluation of neurologic deficits. With a firm suspicion of spinal cord injury, initial treatment should begin with strict attention to averting or minimizing further cord damage. Strapping the animal to a rigid board will enable transporting it in an awake state, while analgesics or heavy sedation (after neurologic assessment) will reduce the patient's discomfort and impulsive thrashing movements. Special care must be exercised when moving the patient with spinal trauma under general anesthesia to prevent further damage.

Glucocorticosteroids have been shown in the cat to combat swelling by stabilizing cellular and lysosomal membranes and protecting intracellular organelles from the effects of hypoxia. They are also thought to reduce the autolytic activity of lysosomal enzymes on neural tissue and to depress posttraumatic catecholamine metabolism and accumulation in the cord. Empirically, corticosteroids have been used as potent anti-inflammatory (antiedemic) agents, and therefore, until proved otherwise, their continued application is justified to treat the inflammation and edema of cord trauma. Hyperosmolar agents such as urea and mannitol have been shown to be clinically effective in the treatment of cerebral edema and experimental spinal cord trauma. These agents reduce edema by raising the intravascular oncotic pressure and promoting renal diuresis. Their use in the early stages of spinal cord trauma is seemingly justified; however, if the animal is hypovolemic or in shock, caution should be exercised to avoid exacerbating these conditions.

Administration of hyperosmolar agents should be discontinued with the attainment of therapeutic levels of anti-inflammatory agents (< 24 hours) to minimize untoward side-effects. Corticosteroids, such as dexamethasone 2 mg/kg every 8 to 12 hours, and a hyperosmolar agent such as mannitol (2 g/kg) administered intravenously are typically the initial treatments of choice.

Treatment rationale, although in the past largely empirical, is becoming increasingly directed at the precise pathophysiology of spinal cord trauma as revealed in animal models of experimental spinal cord compression. It is important for veterinary surgeons to stay abreast of this basic science information to update and fine tune their treatment regimens. Although beyond the scope of this chapter, there exist several recently described approaches to the clinical management of acute spinal cord injury that deserve brief mention. These include anticatecholamine therapy to antagonize the vasogenic central hemorrhagic necrosis, thought to stem from the accumulation of the neurotransmitter norepinephrine; antifibrinolytic agents, such as Epsilon amino caproic acid, to stabilize blood clotting and hemorrhage; pressor agents to maintain adequate cord perfusion on a microcirculatory level; and dimethyl sulfoxide to act as an anti-inflammatory, antiedemic, and vasodilating agent. More experimental and clinical studies need to be carried out before recommendations regarding their use can be made. In summary, the initial treatment of the traumatized patient with spinal cord involvement should be aimed at stabilizing life-threatening conditions followed by medical management to reduce or arrest further cord damage. This necessitates treating cord inflammation and its related vascular phenomena with the hope of achieving cord perfusion and effective chemical decompression of the traumatized site.
DIAGNOSIS
A diagnostic workup includes a thorough physical and neurologic examination coupled with radiographic evaluations as indicated. (10,42,75) The subsequent treatment regimen will be based on this information and the owner's informed willingness to proceed. During the diagnostic workup it is imperative to avoid introducing any further mechanical trauma to the cord by manipulations; however, the diagnostic process should be conducted as rapidly as possible. This necessitates extreme caution in handling the patient.

Radiographs reveal the location of the lesion, the type of lesion (fracture, luxation, or combination thereof), the type of fracture, and the relative displacement of the fragments (usually a fraction of the neural canal dimension). The surgeon should try to estimate the degree of instability as described in the previous sections. A complete evaluation necessitates at least two radiographic projections (ventrodorsal and lateral) but occasionally may require oblique views, tomography, myelography, or manipulation under fluoroscopy. Radiographic evaluation, although essential to diagnostic workup, is incapable of revealing the full extent of spinal cord trauma. For example, traumatic disk prolapse may occur in combination with spinal luxation or may occur separately, particularly in association with so-called impaction injury of the spine, and may not be obvious radiographically. In addition, radiographic images show the spatial anatomical relationships at the time the radiograph is taken and do not demonstrate the excursions that occurred during the traumatic incident. Small subluxations viewed radiographically can be misleading. The spinal cord may also sustain concussion in the absence of fracture as originally described by Holmes in a study of wartime injuries in humans. (44) The mechanism of this injury probably relates to the rapid acceleration and subsequent deceleration of the spinal cord within the confines of the spinal canal, not unlike the cavitation phenomenon observed in high-velocity gunshot injuries. (See Chapter 36.) Such clinical complexities emphasize the importance of a good neurologic examination as part of the diagnostic workup. (10,42,75)

SURGICAL VERSUS NONSURGICAL MANAGEMENT
With completion of a diagnostic workup, the next step is to decide whether to pursue a surgical or nonsurgical course. Much controversy and confusion exist in this area of spinal trauma management, in which equally and eminently qualified surgeons advocate opposing treatment regimens. The ultimate decision is based on information derived from neurologic examination, radiographic appearance, timing of the trauma, and owner compliance.

In the human medical literature, it is generally felt that surgical stabilization of thoracolumbar spinal injuries results in better reduction, better preservation of neural components, and earlier ambulation than the more conservative treatment regimens. (48,49) A vertebral fracture or luxation is considered unstable if, during the healing phase, its fragments are capable of displacement that might produce neural damage or significant angular malunion. Interestingly, no more than 5% of spinal fractures in humans are associated with neurologic deficit. The remaining 95% are simple nondisplaced skeletal injuries associated with relatively brief disability and excellent long-term prognosis. (110,114) In veterinary practice it is likely that many stable spinal injuries without neural damage either are not presented for treatment or are not diagnosed. In cases of spinal injury and displacement with associated neurologic damage, it remains a difficult judgment for the veterinary surgeon to determine which animals would benefit from more aggressive surgical intervention and which are best left to cage rest and/or external fixation.

Although several methods of classifying neurological dysfunction have been proposed, (87,102,104) in general, the empirical and somewhat conservative criteria as put forth by Griffiths (34) are reasonable guidelines to the decision-making process. Patients constituting groups I and II (Table 19-1) with only paresis or paralysis are given conservative medical therapy as initial treatment (as outlined), strict cage rest with or without external fixation, and intensive nursing care. Patients in this category are considered surgical candidates only if there is definite clinical or radiographic evidence of vertebral instability or if their condition deteriorates in the face of medical therapy. Patients in group III (Table 19-1) having paralysis with present but reduced deep pain perception are candidates for surgery if there is evidence of vertebral instability, deteriorating status, or maintained static compression. Animals in group IV with no deep pain sensation and paralysis are thought to have such a poor prognosis that surgery is not indicated. If no improvement in neurologic status is seen within 2 days, euthanasia is advised. (112) This last category may require surgery if, at the owner's request or by the clinician's judgment, an "exploratory" laminectomy is indicated for diagnostic or prognostic reasons.

The objectives of nonsurgical treatment of spinal fractures and luxations are to chemically treat the inflammatory and autolytic destructive process occurring in the neural tissue and to provide immobilization by the use of strict cage rest or external splinting. Surgical management adds to the above objectives the surgical decompression of the cord and internal
stabilization of the spine. Cage rest and other forms of external immobilization, while perhaps minimizing extrinsic forces, are not well suited to counteract intrinsic forces. Internal fixation is clearly superior, with the ability to minimize both. The many and varied techniques for accomplishing these objectives are dependent on the location of the lesion and are discussed in the sections to follow.

NURSING CARE AND REHABILITATION

Whether surgical or nonsurgical management is chosen, the subsequent nursing care and rehabilitation of the paretic or paralyzed patient are essentially the same (see Fig. 19-1) and are critical to the patient's eventual recovery. Animals must be handled with extreme caution, especially in the early phases (< 3 weeks) prior to the attainment of adequate stability through scar formation. Management of the paralyzed patient in both the hospital setting and the home environment is difficult, labor-intensive, and time consuming, particularly for larger dogs. Accordingly, it is imperative that the nursing staff in the hospital as well as those persons in the animal's home who are expected to provide nursing care be fully informed as to the principles of proper management. A simple handout as shown in Figure 10-2 supplies most of the information that an owner needs in the way of nursing care and rehabilitation and should be included with discharge instructions. Bedding must be changed frequently, particularly for those patients suffering urinary incontinence. Water beds or dunnage bags are extremely useful in preventing decubital ulcers. Paralyzed patients should be placed in alternating left and right lateral recumbency every 2 to 4 hours. Bladders should be checked and expressed manually 4 to 6 times daily or, as an alternative, continuous or intermittent indwelling urinary catheters may be employed. Antibiotics to combat secondary retention cystitis are used where indicated, and steroid therapy should be administered for 7 to 10 days in diminishing doses. Dosages of corticosteroids are reduced rapidly to minimize the incidence of the occasional but serious complication of hemorrhagic gastroenteritis.

PROCEDURES FOR STABILIZING THE SPINE

The selection of the optimum method of vertebral stabilization is dependent on the degree of instability (see section on biomechanics) and the location and nature (classification) of the fracture/luxation. The following section will discuss the nonsurgical and surgical techniques of spinal stabilization as they apply to specific injuries and anatomical areas of the vertebral column.

NONSURGICAL TREATMENT

Nonsurgical immobilization of fractures and luxations of the spine in small animals demands skill and ingenuity on the part of the practitioner to compensate for the typically poor cooperation of the paralyzed or paretic patient. Unlike humans, animals are not predictably immobilized when bed rested, nor are they amenable to the standard forms of body casting or skeletal traction. In general, nonsurgical (or external) forms of vertebral immobilization in small animals are mechanically inferior to surgical methods but have the advantages of being inexpensive, noninvasive, and effective when used for the appropriate type of injury. These include fracture/luxations of the spine that meet the following criteria: significant stability and only mild displacement (less than one-third the neural canal); mild neurologic deficits (groups I and II in Table 19-1); and stable neurologic status. From a professional and humane point of view, any fracture/luxation patient retaining even minimal neurologic function, that is, short of cord transection, deserves at least an attempt at this type of management, assuming a surgical course is unacceptable to the owner.

CAGE REST

Following fracture/luxation of the spine, the axial skeleton must be protected from both extrinsic and intrinsic forces acting at the sites of instability, thereby limiting repeated vertebral displacements and further spinal cord damage. Cage rest, while it is the least effective method of minimizing motion at the fracture site, is a clinically effective mode of management for those fracture/luxations having adequate inherent stability. It is best achieved by placing the patient in a small cage having dimensions sufficient to allow standing with ample head room and permitting lateral recumbency with legs in extension. All
the precepts of good nursing care must be followed while managing a paretic or paralyzed patient in a cage or confined area. (See Chapter 10, Nursing Care of the Paralyzed Dog.) In addition to its use as a definitive treatment for certain fractures and luxations of the spine, strict cage rest is also extremely beneficial or essential as ancillary treatment for animals undergoing other primary means of fixation, external or internal.

CASTING AND SPLINTING
The principles of casting or splinting the spine are similar to those employed in the treatment of long-bone fractures. (23,38,40-42,94) The cast or splint must be coapted to the fracture area and have secure points of attachment on either side. It must also be sufficiently rigid to withstand a combination of imposed intrinsic and extrinsic forces. Because the spinal patient is typically very anxious and in pain, back splinting is best accomplished under heavy sedation or general anesthesia. Splints consist of rigid support material, padding, and material to secure these to the animal.

The selection of support material will depend on the size and strength of the patient being treated. Small dogs or cats are easily managed using plaster casts or one of the many commercially available thermoplastic materials, such as Orthoplast or Polyform. Larger dogs require stronger and lighter support materials, such as aluminum sheet. The final configuration of the support material will depend on the site of spinal instability and the inherent properties of the material. Thermoplastic and plaster cast splints may be contoured precisely to the dorsum, whereas aluminum sheet is typically fashioned into a shape resembling the sloped roof of a house.

Careful attention must be directed to adequate padding of the cast or splint. Cast padding (Specialist) or Combine covered with a layer of gauze bandage is usually adequate. Some of the newer foam materials, such as Hexelite padding, have many advantages but are generally more expensive. Areas under the splint prone to pressure sores or ulcerations should be given special attention and padded accordingly. To avoid urine scalding of the skin it is best to keep the paralyzed patient on a grid or porous surface and to position bandaging materials to minimize urine or fecal contamination. Inflamed areas, particularly the perianal and scrotal areas, may be additionally protected by topical medications such as Desitin ointment.

The support materials and padding may be secured to the animal's body by plaster cast, tape, or elastic bandage (Elastikon). Of these, Elastikon is most suitable for this purpose, owing to its elasticity, porosity, light weight, adhesiveness, and low water retention. For adequate purchase on the body, it often must be applied directly to the hair ventrally. Plaster casting has the disadvantages of being difficult to apply, heavy, water-absorptive, and inelastic. Tape, although light in weight, lacks elasticity, does not contour well, and often results in pressure sores if not applied carefully.

As stated above, the application of a neck or back splint necessitates adequate purchase cranial and caudal to the site of instability. At best, this objective can be accomplished only marginally. The head, the thorax (rib cage), the pelvis, and the tail are optimum areas along the axial skeleton to which splints can be adequately attached by bandaging. By firmly securing a rigid member (the splint) between two fixed points, the interposed area is bridged and immobilized. In the case of a thoracolumbar or lumbar fracture, a rigid splint would be fashioned to extend dorsally from the cranial thorax to the pelvis and must be firmly anchored to each. Figure 19-2 illustrates an aluminum back splint fashioned for a dog with a midlumbar fracture/luxation. Note the secure attachment of the dog to the splint in the thoracic and pelvic areas and the ease with which the animal can be safely and conveniently moved or transported. This provides an added margin of security to the animal's owners, who have on occasion adapted a handle to such back splints for ease of carrying.

SURGICAL TREATMENT
The objectives of surgery in the treatment of spinal fractures or luxations are decompression of the spinal cord; reduction of the fracture/luxation; and stabilization via internal fixation. The techniques to accomplish spinal cord decompression are very similar to those used in intervertebral disk prolapse and have been thoroughly discussed elsewhere. It must be noted, however, that traumatic disruption of normal anatomy often complicates an otherwise straight-forward surgical approach.
The two decompressive techniques used most commonly are hemilaminectomy and dorsal laminectomy. The selection of either technique is based on the type of fracture, the lateralization of neurologic signs, and the anticipated method of postoperative stabilization. The technique of hemilaminectomy is in general less destabilizing and spares the dorsal spinous processes if they are to be used for subsequent internal fixation. However, the hemilaminectomy does not provide as wide a visualization of the traumatized cord as does the dorsal laminectomy.

The surgical procedures to stabilize the spine will be reviewed relative to their indications and anatomical sites of applicability in the following sections. Instabilities, malarticulations, and malalignments of the spine such as caudal cervical spondylopathy, lumber-sacral entrapment syndrome, and congenital anomalies have been described elsewhere in this text, and therefore these maladies and the means to stabilize them will be omitted from this section. An exception is the condition of congenital atlantoaxial subluxation, which has not been discussed, and for completeness, will be included in this section.

SPECIFIC FRACTURES AND DISLOCATIONS OF THE SPINE
ATLANTOAXIAL INSTABILITY

Geary, Oliver, and Hoerlein, in 1967,(32) were the first to describe the condition of atlantoaxial subluxation in the canine. Since that time numerous reports and reviews on the disorder have appeared in the literature.(8,29,42) Although the syndrome today is well recognized clinically and many surgical techniques have been advanced to correct the condition, little more is known regarding its etiology and pathogenesis.

The disorder is most frequently observed in small and toy breed dogs. The animals are usually under one year of age but may be presented for this condition later in life if trauma is superimposed upon a previously masked atlantoaxial weakness. The clinical signs are most typically chronic but may be acute in onset. Neurologic dysfunction may range from mild hyperpathia with neck stiffness to frank quadriplegia and respiratory arrest.

The congenital form of atlantoaxial instability is thought to be related to improper embryologic development of the odontoid process of C2 and associated ligamentous structures (Fig. 19-3) (31,32,60,72,76) Three sub types are noted clinically: congenital absence of the dens (Fig. 19-4), fracture or nonunion of the dens with the body of C2 (Fig. 19-5),(60,76) and insufficient ligamentous support of the dens. The purely traumatic form of atlantoaxial instability can be observed in any breed of dog sustaining bending forces and displacements to the cervical region sufficient to cause either a fractured dens or a total rupture of the ligaments holding the dens to the floor of the neural canal of C1 (Fig. 19-6). In either the congenital or traumatic form of the disease, the atlantoaxial instability results in large translational and angular displacements of the C1-2 articulation, particularly in flexion. This produces cord compression by direct impingement of the dens or the body of C2 on the cord (Fig. 19-7). Radiography is necessary to confirm a diagnosis of atlantoaxial instability; however, positioning must be performed with utmost care. The associated neurologic signs and prognosis for treatment are dependent on the severity and duration of the cord compression.

Neck splinting for 3 to 4 weeks, particularly for animals having mild neurologic deficits, commonly results in significant functional improvement. However, the underlying instability remains, and thus recurrence is common. Accordingly, it is generally accepted that atlantoaxial instability is most effectively managed by surgical intervention.


Surgical methods to treat atlantoaxial subluxation are directed at eliminating all bending and translational motion between the atlas and axis. Any of the techniques involving the dorsal approach may be accompanied by hemilaminectomy if surgical decompression of the cord or visualization is indicated. Hemilaminectomy is accomplished through the use of rongeur or air drill, by excising the craniolateral lamina of C2 and the caudolateral lamina of C1. Ventral techniques for decompression require slotting the ventral arch of the atlas and excision of the odontoid process if present. For mild cases of atlantoaxial subluxation with minimal neurologic compromise, decompression is often unnecessary if adequate reduction and stabilization of the C1-2 articulation can be achieved surgically.

DORSAL TECHNIQUES

The most commonly used corrective surgical technique for atlantoaxial instability is the single- or double-strand wiring of the involved C1 and C2 vertebrae via a dorsal approach, as originally proposed by Geary and associates in 1967.(37) Occasional wire breakage has resulted in modifications of the technique incorporating methylmethacrylate bone cement(81); nonmetallic, nonabsorbable suture material(6); or the nuchal ligament.(62) Mechanical principles of the repair, however, remain the same. A tension suture is placed from the dorsal spine of C2 to the neural arch of C1 to replace the combined mechanical function of the dorsal atlantoaxial ligament and the ligaments to the dens.

The basic technique requires the dog to be positioned in sternal recumbency with the head secured to a sandbag or other elevated padded surface to maintain position during the operation. A dorsal midline incision is made extending from the occipital protuberance to the level of the fourth cervical vertebra. The paraspinal musculature is incised and separated along its median raphe exposing the dorsal arch of C1 and the dorsal spinous process of C2. Reflection of the musculature and periosteum from C1 and C2 is continued ventrally and laterally, with care taken to avoid the vertebral artery and cervical nerve roots (Fig. 19-8).(72)


FIG. 19-7 Radiograph of an atlantoaxial subluxation suggests marked cord impingement.

FIG. 19-8 Lateral view of atlantoaxial area illustrates major structures, including arteries and nerves in the vicinity of the surgical site. (A, vertebral artery; B, cerebrospinal artery; C-1, first cervical nerve; C-2, second cervical nerve) (Oliver J E, Lewis RE: Lesions of the atlas and axis in dogs. J Am Anim Hosp Assoc 9:304, 1973)
The epidural space is exposed by incising the dorsal atlanto-occipital and atlantoaxial membranes without injuring the underlying dura and spinal cord. If indicated, a hemilaminectomy can be performed at this time, making certain to leave a sufficient amount of the neural arch of C 1 to prevent wire pull-out and consequent fixation failure. To gain additional exposure for eventual passage of wire, the caudal margin of the occipital bone or the cranial margin of the atlas may be removed with rongeurs.

Two holes are drilled in the dorsal spine of the axis using minimal force to avoid aggravating the underlying instability and cord compression. A 24-gauge orthopaedic wire loop is passed under the arch of the atlas from caudal to cranial and grasped at the atlanto-occipital space as shown in Figure 19-9. Sufficient wire is pulled through to allow folding back of the loop to the spine of the axis. The wire loop is cut and the ends passed through the predrilled holes in the spine. Accurate reduction of the atlantoaxial articulation is maintained by an assistant while the ends of the wires are twisted (Fig. 19-10). Alternatively, the wires may be placed and secured as shown in Figure 19-11. To avoid the technical difficulties in longitudinal wire passage, Hoerlein advocates drilling transverse holes in the neural arch of C1 and fastening the wires of C2 in a fashion similar to that described above (Fig. 19-12).

All techniques, wire or nonwire, are reported to yield adequate stability and prevent further cord compression in most cases. Complications include pull-out of the suture through the narrow neural arch of C 1 (81) and material failure of the suture. (6,32,63,105)Postoperatively, a neck splint is indicated to further immobilize the cervical spine and to reduce the stresses on the internal fixation. The splint may be made of bulky cotton padding applied from the head to the thoracic inlet, or of plaster, aluminum, or thermoplastic material secured dorsally from the skull to the thorax. Ancillary therapy may include...
drug administration as discussed in the initial treatment of spinal injuries and conscientious nursing care.

VENTRAL TECHNIQUE
Recently, a technique has been described for ventral decompression, internal fixation, and bony fusion of the atlantoaxial area in the dog. The method eliminates some of the complications stemming from dorsal wire fixation, namely, breakage or pull-out. It also provides for rigid internal fixation and subsequent bony fusion of C1 to C2 as recommended in humans for similar conditions.

The atlas and axis are approached ventrally according to the method of Swaim. The proximal humerus and the ventral cervical region from the intermandibular area to the manubrium of the sternum are prepared for aseptic surgery. The patient is positioned in dorsal recumbency with the head and neck extended and the forelimbs pulled caudally. A midline skin incision is made from the intermandibular area to the level of the fourth cervical vertebra. The sternothyroid muscles are separated along their midline to reveal the larynx, trachea, thyroid glands, esophagus, common carotid artery, and vagosympathetic trunk. These structures are carefully mobilized and retracted laterally along with the ventral cervical musculature. The longus colli muscles, immediately ventral to the atlas and axis, are bluntly dissected along the midline, separated from their bony attachments, and retracted laterally.

The ventral arch of the atlas is removed with rongeurs to 0.5 cm on each side of the midline. The odontoid process is excised through the slot in the atlas using a pneumatic high-speed burr. Remaining ligamentous attachments are sharply dissected to facilitate complete removal of the odontoid process and visualization of the ventral aspect of the spinal cord.

The atlantoaxial articulation is prepared for bone grafting by curetting or scraping the articular cartilage from the subchondral bone on the caudal surface of C1 and the cranial surface of C2. Cancellous bone is harvested from the proximal humerus and packed into the prepared site. Atlantoaxial alignment is achieved and maintained through the use of small-fragment forceps. Kirschner pins (0.45 inches or 0.625 inches) are directed either by hand chuck or power drill bilaterally from the body of the axis across the atlantoaxial joint and into the atlas. Optimum pin placement is accomplished by starting the pin close to midline on the caudoventral body of the axis and directing it to a point just medial to the alar notch on the cranial edge of the atlas. Ideal pin placement is shown in Figures 19-13 and 19-14.

Closure consists of opposing muscle, subcutaneous tissue, and skin. No neck splinting is required; however, cage-confinement is recommended. Results of experimentation on the use of this technique demonstrated rigid to firm joint stability at 6 weeks postoperatively in 10 of 12 experimental animals while all six control animals remained completely unstable. The authors concluded that the ventral pinning technique affords adequate stabilization, allowing for dorsal ligamentous healing and vertebral body fusion, thus providing a permanent solution to atlantoaxial instability.

CERVICAL VERTEBRAL FRACTURES
Traumatic fracture/luxation of the cervical spine is encountered in small animal practice but with much less frequency than thoracolumbar injuries. The most common causes include automobile contact, dog fights, and gunshot injuries. Animals...
present with neck pain or neurologic deficits reflecting the level and magnitude of vertebral displacement. Marked cord compression may result in respiratory paralysis and death. A small or radiographically subtle cervical instability may cause only slight motor ataxia or pain. If instability persists, the animal may demonstrate, over a period of days, a gradual decline in neurologic function reflecting repeated cord trauma from unrestricted motion at the site of spinal instability.

In a recent survey of cervical fractures in the dog, 27 total cases were reported in the veterinary literature. Interestingly, 89% of these fractures involved C1 or C2 or both. The remaining 11% occurred from C3 to C7. The axis was the most frequently affected (78%), with the dens and/or body most commonly involved (86%). Very recently a case of traumatic atlanto-occipital fracture/luxation in a cat was reported.

The high relative incidence of fractures of the axis, particularly involving the vertebral body and pedicles, is attributable to the anatomical lack of dorsal facet joints between C1 and C2, the poor dorsal ligamentous and tendinous support relative to the axial spine cranially and caudally, and the weak ultimate (inertial) properties of the cranial body of C2, particularly in axial bending.

As discussed above, prognosis of cervical fractures is based on case history, physical and neurologic examination, and radiographic evaluation. Because of the intricate shape of the vertebrae throughout the spine, an accurate diagnosis of the site and severity of cervical fracture/luxation is often difficult from survey radiographs alone. It may be necessary to perform oblique projections, tomography, myelography, or, in rare cases, careful manipulation under fluoroscopy. One must remember to use extreme care in handling a patient with suspected vertebral instability, particularly when the patient is under anesthesia, to avoid iatrogenic spinal cord trauma.

The treatment objectives in managing cervical fracture/luxations include decompression, reduction, and stabilization. In the absence of cord compression, it is sometimes possible to achieve adequate reduction and immobilization by external means, such as a neck splint or brace. The use of skeletal traction, such as the halo frame used in human patients, is precluded in the dog by the absence of a well-developed shoulder girdle and the unwieldy nature of the apparatus. Enforced cage rest is an effective treatment regimen if it can be determined that there is sufficient inherent stability of the cervical spine to prevent major vertebral displacement during the healing phase.

The general indications for surgical intervention in cervical fracture/luxations include severe neurologic signs, a progressive decline in neurologic status, obvious vertebral instability (radiographic or clinical), and the persistence of pain or ataxia. The cervical spine can be surgically approached dorsally or ventrally depending on the nature of the fracture and the type of fixation to be used. Occasionally, both dorsal and ventral techniques are necessary, but the combination may result in significantly increased cervical instability.

In general, the cervical vertebral column presents many complexities to adequate operative immobilization. The vertebrae are composed of thin bony processes, pedicles, and facets. Also the vertebral bodies are small and largely cancellous, offering only marginal purchase for screw or wire fixation, particularly cranial to C3. The large surrounding muscle mass has the capacity to generate high intrinsic bending and compressive forces on the cervical spine, thereby increasing potential for failure of the fixation, which, by necessity, must be applied eccentrically. These considerations are magnified when extrinsic forces are taken into account, such as those associated with postoperative management.

It is safe to generalize, therefore, that in the case of cervical instability, any form of fixation is at best marginal. Given the wide variety of fracture/luxations and associated trauma, there exists no one standard means of internal fixation. It remains for the surgeon to select the technique or techniques of stabilization that yield the optimum immobilization. Because of the limited stability of internal fixation of the cervical spine, it is recommended that all fixation methods be supplemented with external casting or splinting and strict cage confinement for a minimum of 3 to 4 weeks.

Based on a review of the veterinary literature, Table 19-2 summarizes the various immobilization techniques in small animals relative to site of cervical fracture/luxation. The location and type of fracture/luxation dictate the method or methods of internal stabilization. Few guidelines exist as to the optimum surgical management of any given fracture/luxation, except for the uncomplicated atlantoaxial luxation as described above. Often the surgeon must improvise, using the methods and instrumentation available to him. It is not uncommon to encounter a traumatic cervical instability that is beyond surgical correction. In such a case, if associated with only minimal neurologic dysfunction, it may be feasible only to apply some form of external neck fixation followed by strict cage confinement, in the hope that the process of healing will in time yield a functional stability.
The mechanics of the cervical spine, either in its normal or in a traumatically unstable state, are poorly investigated in both human and veterinary literature. The only comparative study appearing in the veterinary literature is a qualitative evaluation of cervical stability relative to four techniques of spinal fixation in dogs, reported by Swaim in 1975.\(^{(32,98)}\) The four techniques investigated were bilateral screws through the articular processes of C4 and C5, bilateral wires through the articular processes of C4 and C5, bone screw in the vertebral bodies of C4 and C5, and ventral vertebral plating of C4 and C5. Stability of fixed spines was assessed after 14 days by gross examination of dorsal-ventral stability at the C4-5 interspace. Results were compared with control spines, which were subjected to varying degrees of disarticulation at C4-5. The author's findings suggest that dorsal cervical fixation with screws provided more solid vertebral fixation than did the other forms of spinal stabilization. Ventral cervical fixation with plates was considered an inferior fixation technique and was associated with several complications, including screw tips in the neural canal, screw back-out and migration, plate separation from the vertebrae, and an inability to perform concomitant ventral spinal cord decompression. Ventral cervical lag screw fixation also provided inferior stability and was plagued with technical problems relative to screw placement. The technique of dorsal cervical fixation with wires was regarded as unsatisfactory. In the control dogs, marked cervical instability was created either by cutting the intervertebral disk alone or by cutting the disk in combination with dorsal laminectomy and elimination of dorsal ligamentous structures including the joint capsules. Interestingly, the remaining muscular and ligamentous attachments between the two adjacent vertebrae afforded enough stability to prevent cord compression and related neurologic deficits.

It is recognized that decompression by laminectomy or hemilaminectomy decreases the stability at the vertebral articulation.\(^{(47)}\) For this reason, decompression of cervical fracture/luxation is recommended only if there are cord-compressing laminar fractures or if the fracture fragments or a displaced body fracture cannot be reduced adequately.\(^{(93)}\) Fractures of the cranial cervical spine, particularly C1 and C2, are best approached, reduced, and stabilized via a dorsal approach and wiring (Table 19-2). The large dorsal spinous process of C2 provides adequate purchase for wire fixation assuming there exists sufficient bone cranially or caudally to fasten the wire for stability. If such is not the case, a ventral approach with slotting, pinning, and bone grafting may be required.\(^{(90)}\)

Caudal to C2, the dorsal spinous processes are too small for substantial plate or wire fixation, and therefore the technique of bilateral screws through the articular processes appears to offer the greatest stability.\(^{(95)}\) This procedure involves a dorsal approach to reveal the dorsal spinous processes and dorsal lamina of the affected cervical articulation. The dissection is extended bilaterally to expose the lateral edges of the articular processes. A self-retaining retractor aids in holding the musculature away from the operative area. A hole is drilled beginning centrally on the caudal articular process of the cranial vertebra and directed caudoventrally and slightly laterally to penetrate the articulation and apposing joint surface of the cranial articular process of the caudal vertebra. Drilling is stopped abruptly after breaking through the cortical bone laterally to avoid the vertebral vessels and cervical nerve roots. The hole is measured and tapped and a cortical (full-threaded) screw is inserted. The procedure is repeated on the contralateral articular process (Fig. 19-15). This technique has the advantage of permitting a simultaneous dorsal decompressive laminectomy.

In the absence of intact dorsal articular processes, a ventral approach to the cervical spine may be considered as an alternative
for fracture/luxations from C3 to C7. The many techniques described for ventral fixation of the spine are all modifications of the original technique as described by Cloward. (7) Surgical aims are to decompress the spinal cord ventrally, reduce the fracture/luxation, and insert a bone graft into the prepared slot while providing enough stability either internally or externally to facilitate a complete bony fusion. (56) The ventral fixation techniques of the canine cervical spine have been described in the treatment of animals with caudal cervical spondylopathy and therefore will not be discussed here. Ventral decompression alone may be indicated for treatment of cervical trauma to remove extruded disk material. Traumatic rupture of the intervertebral disk has been shown to be a frequent sequela to fracture luxations of the cervical spine in humans. (106) Ventral decompression may also be critical to spinal cord survival in cases of fracture/luxation that have large displacements and that are not reducible surgically.

THORACIC AND LUMBAR FRACTURE/LUXATIONS
The most common sites of fractures and luxations of the spine in small animals are the thoracic and lumbar vertebrae. (17,42,99) The prognosis and treatment for this type of injury are based on the nature and extent of the injury, an awareness of the pathophysiology of spinal cord compression, and a knowledge of fixation techniques and their efficacy.

SPINAL IMMOBILIZATION
Many surgical techniques to immobilize the thoracolumbar spine appear in the veterinary literature. Most methods have been developed empirically, and the specific indications for their use have been poorly defined. An understanding of the capabilities and limitations of current spinal fixation methods is imperative to the appropriate treatment of injuries of the spine. In the absence of quantitative comparative biomechanical testing of these methods, the veterinary surgeon must use common sense and an intuitive understanding of fracture mechanics in selecting the appropriate procedure or combination of procedures to achieve spinal stabilization (see section on biomechanics of the spine and spinal injuries).

In a limited, qualitative evaluation of the methods of spinal fusion and vertebral immobilization in the dog, Hoerlein(39) in 1958 concluded that application of plates and screws to the dorsal spinous processes was the most satisfactory surgical procedure. However, the immobilization achieved by each technique tested was marginal at best, and ancillary external fixation was also indicated. Since this early work, many new stabilization techniques have been introduced, including vertebral body plating,(95,96) plating of the dorsal spinous processes using plastic plates,(4,15,65,66,115,116) polymethylmethacrylate (PMMA) and pin composite fixation(95), cross-pinning(25), stapling(27), transilial pinning(39), and others.(22) In spite of these developments and improvements, the techniques, in general, remain limited by the inherent anatomical and mechanical characteristics of the spine. By necessity, supplemental external fixation or enforced cage rest is still soundly recommended to preserve surgical reduction and fixation.

The thoracolumbar fractures and luxations encountered in small animal practice present with widely varying degrees of instability and associated pathomechanics. Moreover, instability is not easily diagnosed prior to surgery or even with surgical exploration, making the selection of a rational treatment regimen difficult. For purposes of simplification, spinal instability can be divided according to the type of resultant deformity (angular or translational) and the associated anatomical structural deficits (dorsal components, ventral components, or combined) as described previously. Table 19-3 lists recommended treatment alternatives for hypothetical spinal structural deficits based on theoretic considerations gained from the pathomechanics of the human cadaver spine(50,88) and clinical experience. It should be kept in mind that these guidelines are based on mechanical principles and may change as new information and techniques become available. Important factors in the selection of the appropriate method of fixation are the site and mechanical function of the failed vertebral components. If, for example, the dorsal stabilizing components (neural arch, articular processes, and dorsal ligaments) are selectively lost (these structures act in tension to limit the extent of the spinal flexion), the spine can be expected to exhibit a kyphotic angular deformity. Angular instabilities, assuming no concomitant disk prolapse, do not compromise the spinal cord as frequently as translational instabilities, and surgical correction may be clinically unnecessary. If surgical correction is indicated based on neurologic damage, an appropriate selection of corrective technique is one that would be capable of transmitting tensile forces across the area of instability, such as plating of the spinous processes. The placement of a stainless steel plate on the vertebral body in this instance, although perhaps successful clinically, would not have the same mechanical advantage in resisting spinal flexion. The plate would be subjected to large bending movements with the potential for premature failure. Similar conceptual rationale can be adapted to selective ventral instability or combined (complete) dorsal and ventral instability.

Complete vertebral injuries are typically associated with translational instabilities and, if of sufficient displacement (one-third
to one-half neural canal) may result in severe cord compression. Fixation is directed at counteracting the intrinsic and extrinsic forces that tend to displace vertebral bodies and narrow the neural canal. Such fixation is optimally located on the vertebral bodies, where the bulk of bone exists for screw or pin purchase and where the application of compressive forces, such as with compression plate fixation, maximizes the resistance to shearing of the fractured or luxated fragments.

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<th>TABLE 19-3 Recommendations for Thoracolumbar Spine Immobilization Relative to Type of Instability</th>
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The region of spinal fracture/luxation will also influence the selection of immobilization technique. For example, spinous process plating is dependent on adequate strength and size of dorsal spinous processes. The lumbosacral junction, therefore, is not optimally immobilized using this procedure owing to the small dorsal spines of the sacrum. Similarly, vertebral body plating is used less easily in the thoracic spine, where rib heads interfere with application, and in the lumbosacral spine, where the sacral body is both small and inaccessible from the dorsal approach.

It is apparent from the information in Table 19-3 that except for the "worst case" instability (38), a wide variety of methods of internal and external fixation may function adequately to immobilize the spine. A complete loss of dorsal and ventral components, including structural absence of the vertebral body, however, is more critical. Only one technique is presently recommended for such injuries, namely, dorsolateral vertebral body plating with supplemental bone graft. The other forms of dorsal fixation may be used in conjunction with vertebral body plating to optimize rigid stability.(83)

### SPINAL PROCESS FIXATION

Plate fixation on the easily accessible dorsal processes of the spine represents one of the earliest historically acceptable means to accomplish vertebral stability.(3,37,39,46,65) Today plates are manufactured of either metal (stainless steel 316L and Vitallium) or plastic (polyvinylidine fluoridet). So applied, they provide resistance to flexion and rotation, which is limited by the relative weakness of the spinous processes and the stiffness of the implant. Plastic plates, in comparison with metal plates (Fig. 19-16), allow interspinous rather than intraspinous screw fixation and provide better plate-to-bone contact. Also they are not as rigid. These properties tend to reduce the common complications of spinous process fractures and screw pull-out from the bone.(4,15,65,66,115,116)

![FIG. 19-16 Diagrammatic sketch of two types of plates attached to the canine spine. Metal spinal plates are held in position by passing bolts through the spinous processes and the plate on each side (above). Plastic spinal plates are held in position with their friction grip surfaces against the bone by placing bolts between, rather than through, the processes (below). Flexibility of the plates allows for greater bone-plate contact than is possible with metal plates. (Yturрасpe DJ, Lumb WV: The use of plastic spinal plates for internal fixation of the canine spine. J Am Vet Med Assoc 161: 1651, 1972)](image)

Plates are best applied in matched pairs and should extend at least two and preferably three vertebral segments to either side of the fracture/luxation.(115) Limitations arise in the lumbosacral area because of the small dorsal processes of the sacrum. A recently developed adaptation combines spinal plating with transiliac pinning for lumbosacral fracture/luxation(14) (Fig. 19-17). In larger dogs, plates may be secured directly to the sacrum via bolts passing through the medial sacral crest.(99) The surgical approach for plating the spinous processes is the standard dorsal approach through the skin and lumbodorsal fascia. (78) Yturрасpe and Lumb have advocated bilateral parallel incisions through the dorsal fascia 3 cm off the midline to provide for adequate coverage of the spinal plates after they are applied and to prevent plate slippage dorsally.(115) Both approaches, however, find widespread use and acceptability. In the standard approach, the multifidus, interspinalis, and longissimus muscles are bluntly dissected from the dorsal spines to the level of the articular facets, preserving the muscle attachments to the articular processes. To assure optimum plate-to-bone contact, particularly in the caudal thoracic area, the dorsal lamina
may require grooving with a high-speed air drill or rongeur. This allows placement of plates as close to the base of the spines as possible, facilitating screw positioning for metal plates and maximum plate-to-bone contact for plastic plates.

Metal plates are fastened via bolts through predrilled holes in the spinous process (Fig. 19-18).(42) Bolts are tightened securely, but excessive force should be avoided to prevent fracture or crushing of the spine. Excess bolt length is trimmed with a pin cutter and the ends filed. The use of a single metal plate screwed or bolted to the dorsal spinous processes unilaterally provides dramatically inferior structural stability and should be discouraged.(39,40)

Plastic plates are applied with the friction-grip surface against the spine and secured in place with bolts passing between the spinous processes (Figs. 19-16 and 19-19). Bolts are tightened until the plates are in firm contact between the spinous processes. With the vertebrae cranial and caudal to the fracture/luxation reduced and stabilized adequately, supplemental wiring of fracture fragments to the plate using 18- to 20-gauge wire may be indicated. Bone grafting may also be performed to augment long-term stability.(45) The dorsal fascia, subcutaneous tissue, and skin are closed routinely. As discussed above, it is advisable to protect the stabilized spine with a supplemental external splint or cast for a minimum of 3 to 4 weeks. The complications leading to failure of spinous process plating are screw pull-out, plate slippage, and spinous fracture.

FIG. 19-17 Diagram showing relationship between plastic plates and transilial pins. (Yturрасpe DJ, Lumb wv: The use of plastic spinal plates for internal fixation of the canine spine J Am vet Med Assoc 161 1651, 1972)

FIG. 19-18 Application of metal plates for stabilization of the spine. (A) Drill holes are made in the spinous processes after the plates have been positioned so that bolts will afford the greatest stability and immobilization. (B) The plates and bolts have been secured to effect skeletal immobilization; at least three and occasionally four or five vertebrae should be incorporated in the plate application. Bolts should be placed in the thickest portion of the spine as close to the lamina as possible for most effective stabilization. (C) Dorsal view of illustration in B (Hoerlein BF: Canine Neurology. Philadelphia, WB Saunders, 1978)


SPINAL STAPLING

Spinal stapling as proposed by Gage(27) is a method of spinal immobilization in small dogs (under 15 lbs) that utilizes a small stainless steel pin as a semirigid member secured by wire to the dorsal spines (Fig. 19-20). The technique affords
reasonable immobilization in small dogs and cats for all types of instabilities except those involving a structural loss of the vertebral body. The surgical approach is performed in a manner similar to that described for spinous process plating. If necessary, a hemilaminectomy may be performed prior to surgical stabilization. Small holes are drilled in the base of the vertebral processes at least two, and preferably three, segments cranial and caudal to the site of instability. A small diameter stainless steel pin (0.045 cm-0.062 cm in diameter) is bent to fit through the most cranial and most caudal holes so that the pin acts as a tension band constraint to flexion (Fig. 19-20). Stainless steel wire (22- to 24-gauge) is used to secure the pin to the intervening spinous processes. The dorsal lumbar fascia, the subcutaneous tissue, and the skin are closed in a routine fashion. An external splint or cast is applied for a period of 2 weeks.

To achieve additional support, Swaim(99) has modified Gage's technique to include a U-shaped Steinmann pin that runs bilaterally on either side of the spinous processes (Fig. 19-21).

FIG. 19-20 Spinal stapling technique. (A) Small-diameter stainless steel pin bent at right angles approximately 2 cm to 3 cm from the ends is passed through predrilled holes in the dorsal spinous processes cranial and caudal to the site of instability. (B) The ends of the pin are bent back against the spinous processes, and stainless steel wire passed through predrilled holes in the dorsal spinous processes is twisted to secure the pin to the processes of the intervening vertebrae. (C) Dorsal view of spinous processes fixed by stapling technique. (Swaim SF: Thoracolumbar and sacral spine trauma In Bojrab MJ (ed): Current Techniques in Small Animal Surgery. Philadelphia, Lea & Febiger, 1975)

FIG. 19-21 Alternative stapling method. (A) A U-shaped pin is passed through a hole in the caudal-most spinous process and positioned symmetrically on either side of the dorsal spines. (B) Similar to Figure 19-20. Stainless steel wire has been passed through predrilled holes and twisted to secure both legs of the pin to the dorsal spinous processes. (Swaim SF: Thoracolumbar and sacral spine trauma In Bojrab MJ (ed): Current Techniques in Small Animal Surgery. Philadelphia, Lea & Febiger, 1975)

VERTEBRAL BODY FIXATION
The desire to develop methods of spinal stabilization by vertebral body fixation stems from the relatively abundant osseous tissue available for screw or pin purchase and the clinical complications frequently associated with spinous process fixation. Many techniques utilizing vertebral body fixation have been reported in the literature, including dorsolateral vertebral body plating,(95,96,99) pin and PMMA stabilization,(85) cross-pinning,(25) closed para-anal intramedullary pinning,(22) and ventral vertebral body plating.(39) Only the first three have received common clinical use.

VERTEBRAL BODY CROSS-PINNING, as originally described by Gage,2s involves inserting small stainless steel intramedullary pins into the vertebral bodies, traversing the site of the instability to achieve immobilization of the spine. Surgical exposure consists of a dorsolateral approach on one side of the spine, blunt dissection of musculature from the dorsal
processes, and sharp dissection of the muscular attachments to the articular processes. Blunt dissection and lateral retraction of muscle are continued ventral to the level of the transverse processes or rib heads. Care should be taken to protect the spinal nerves and vessels emerging from the intervertebral foramina. A hemilaminectomy should be performed if spinal cord compression is suspected.

Pin size is determined by the size of the dog; 0.045 cm to 0.062 cm in diameter for dogs 15 kg or less and 0.1 cm to 0.2 cm in diameter for larger dogs. Pin placement is dependent on the type of injury. For instabilities at or near the intervertebral space, two pins are crossed diagonally, with firm fixation in the vertebral bodies cranial and caudal to the involved space (Fig. 19-22). Fractures involving the diaphysis of the vertebral body, such as compression-type fractures, necessitate pin placement spanning three vertebral bodies and two interspaces. One pin is inserted through the body just cranial to the fractured vertebra and directed caudally into the middle of the fractured vertebra crossing the fracture line. A second pin is directed from the caudal vertebral body cranially (Fig. 19-23). Both techniques require pin insertion starting in the middle of the vertebral body, which for lumbar vertebrae begins just dorsal to the lateral processes, and for thoracic vertebrae, through the dorsal aspect of the ribs. From this point, pins are directed diagonally and ventrally to avoid the vertebral venous sinuses and to be certain to cross the site of instability. Pins are cut as closely to the vertebral body as possible. Bone grafting may be indicated to facilitate fusion. Closure is performed in a routine manner. An external support splint is recommended for 3 to 4 weeks.

The technique of cross-pinning is more difficult in the thoracic area because of the ribs. Pin placement must be performed with an awareness of vital structures ventral to the vertebral column, including the aorta, vena cava, and lungs. The technique, although not optimally suited to limit angular deformities of the spine, yields excellent resistance to shear and translational displacement. When combined with suitable external support to limit bending, this technique provides adequate spinal immobilization. It is not recommended for the treatment of comminuted vertebral body fractures capable of collapse.

FIG. 19-22 Technique of vertebral body cross-pinning. (a) Two segments of intramedullary pin have been inserted in the vertebral bodies in a cross-pin fashion to immobilize an epiphyseal fracture of T13. Two vertebrae have been immobilized. (b) A dorsoventral view of the cross-pin technique to immobilize two vertebrae.


VERTEBRAL BODY PLATES
Plating of the vertebral bodies was originally described by Swaim in 1971. The technique remains basically unchanged today. The surgical approach is similar to that described for crosspinning except that the incision and muscle dissection are lengthened to include visualization of three complete intervertebral spaces. It is carried ventrally to the level of the transverse processes in the lumbar spine and the costovertebral junctions in the thoracic area. Spinal vessels and nerve roots emerging from the intervertebral foramen should be isolated and protected, except those that would be directly compromised by plate application. These should be ligated and transected. Care must be used to avoid damage to nerve roots of the major peripheral nerves. If indicated, a hemilaminectomy is performed.

The rib heads present some difficulty in plate placement in the thoracic spine. These must be retracted ventrally after being cut with a bone-cutting forceps. Following plate application, a wire is inserted into a predrilled hole in the rib head and fastened to the dorsal spinous process. This will secure the rib head in a more cosmetically acceptable position (Fig. 19-24). In the lumbar area, the dorsolateral surface of the vertebral bodies requires no special preparation prior to plate application.

FIG. 19-23 (a) Cross-pinning technique used to immobilize a transverse fracture of L1. Three vertebrae have been immobilized. (b) A dorsoventral view of the cross-pin technique used to immobilize three vertebrae. (Swaim SF: Thoracolumbar and sacral spine trauma. In Bojrab MJ (ed): Current Techniques in Small Animal Surgery. Philadelphia, Lea & Febiger, 1975)
Selection of the correct plate size and length is based on the size of the dog and the length of structural deficit. In general, the same principles of internal fixation as applied to long-bone fractures should be utilized for plate and screw fixation of the thoracolumbar spine. (68) Optimally, four cortices of screw purchase should be placed in each vertebral body. At times this will necessitate spanning more than just two vertebral segments (Fig. Fractures and Luxations of the Spine 19-25). If obvious bony or structural deficits are apparent, bone grafting is indicated.

Screw holes are predrilled beginning on the dorsolateral surface of the vertebral body. The drill is directed perpendicular to the axis of the spine and somewhat ventrally to exit on the opposite ventrolateral cortex (Fig. 19-26). Following reduction, stabilization, and bone grafting, the surgical site is closed routinely. Such fixation also provides adequate angular and rotational stability and excellent translational stability. The technique of vertebral body plating is limited in its regional applicability. The vertebral bodies are not easily exposed in the cranial thoracic area. Likewise Swaim has shown that transection of nerve roots caudal to the fifth lumbar vertebra results in noticeable neurologic deficits in the distribution of the lumbosacral plexus. (95) Therefore, unless nerve roots can be preserved, dorsolateral vertebral body plating should be avoided in this region.

This method is versatile in its applicability to many types of vertebral instabilities (Table 19-3). Its major advantage lies in its ability to withstand compressive forces transmitted along the vertebral bodies. It is the preferred fixation for fracture/luxations exhibiting vertebral body collapse and shortening.

PMMA/PIN COMPOSITE FIXATION
To circumvent some of the anatomical limitations of vertebral body plating and the difficulty of pin placement in cross-pinning, Rousess has proposed a method of spinal immobilization using pins in the vertebral bodies, stabilized by an interconnecting bridge of PMMA. Its advantages lie in ease of application and its capacity to be adapted to any site along the thoracolumbar spine. The surgical approach consists of a routine dorsal exposure (78) after which a dorsal laminectomy is performed for decompression. Two bilateral pins (3/32 inch-1/8 inch) are placed securely into the vertebral bodies cranial and caudal to the instability beginning on the dorsolateral aspect of the midbody and angled as shown in Figure 19-27. Pins are cut at the height of the articular processes and the surgical site is prepared for the application of PMMA. Adequate exposure and a dry surgical field are necessary. The spinal cord is protected from the chemical and thermal effects of the PMMA by a covering of saline-soaked Gelfoam. The luxation is reduced and held in anatomical alignment using suitable bone clamps prior to mixing and applying the PMMA. The PMMA polymerization process requires 4 minutes of mixing and 9 to 11 minutes of hardening. The material is ready for handling when it will not stick to the surgeons' gloves. It should be formed into a long cylinder approximately 1 cm to 2 cm in diameter and laid around the laminectomy defect incorporating the pins.
While still soft, the PMMA is further molded to contour to the shape of the vertebral column and to incorporate the articular processes. While the PMMA is passing through its exothermic phase, the surrounding tissues should be irrigated with iced lactated Ringer's solution to prevent thermal damage and necrosis. The muscles, dorsal fascia, and skin are closed routinely.

This method of fixation provides vertebral stability that is similar to that associated with plating of the dorsal processes yet yields an added component of rotational stability. It is not as rigid as vertebral body plating, however, and is not optimally positioned to withstand large compressive forces in the case of structural vertebral body deficits. The technique should be reserved for those instabilities with an intact ventral buttress.

**FIG. 19-27 PMMA pin composite fixation.** (A) Illustration of the lateral thoracic spine shows pin placement into the vertebral bodies prior to application of PMMA (B) Illustration from the cranial aspect of a thoracic vertebra (left) and a lumbar vertebra (right) shows how pin placement is influenced by morphologic variations. The relatively thick pedicles of the thoracic vertebrae allow pin placement to originate dorsal and lateral to the vertebral canal, while in the lumbar vertebrae the pins originate on the dorsolateral aspect of the vertebral body. (C) An illustration of the lateral thoracic spine shows the placement of the PMMA (shaded area) around the pins. (Rouse GP, Miller JI. The use of methylmethacrylate for spinal stabilization J AmAnimHospAssoc 11:408, 1975)

**LUMBOSACRAL FRACTURES**
Fractures and luxations of the lumbosacral area are observed with relatively high frequency in small animal practice and typically result from direct trauma to the hind end. Although a variety of traumatic displacements may present in this area, the caudal sacral segment is most often displaced cranially and ventrally with respect to the cranial lumbar segment. Neurologic deficits reflect the degree of cord impingement. Interestingly, fractures in this area can be grossly displaced yet manifest minimal neurologic involvement. Such injuries often respond satisfactorily to conservative management. (30,89)

Slocum and Rudy, (89) in 1975, introduced the technique of transilial pinning to limit the extent of lumbosacral displacement in the typical cranial ventral lumbosacral fracture/luxation. The surgical approach consists of exposing the lamina, dorsal spinous processes, and caudal articular facets of the seventh lumbar vertebra as well as the median sacral crest, the cranial mammilloarticular process, and the cranial articular facet of the sacrum. The exposure of the sacrum may be compromised because of its cranioventral displacement.

Reduction is accomplished by traction on the head and tail by unscrubbed surgical assistants and elevation of the sacrum into its normal position. A transilial pin penetrating both wings of the ilium dorsocaudal to L7 maintains reasonable reduction (Fig. 19-28) and prevents cranioventral migration of the sacral segment. The pin is inserted directly through the gluteal musculature laterally, over the caudal lamina of L7, and embedded in the contralateral ilial wing. Closure is routine.

The technique, although not providing rigid stability at the L7-S1 junction, has resulted in gratifying clinical results. (89) The occasional complication of pin migration can be avoided by the use of the threaded screw and nut.

Plating of the dorsal spinous process using plastic plates has been described, (99) and recently a technique combining plastic plates and transilial pins has been introduced. (14) The approach for either of these techniques is identical to that used for transilial pinning, as is the process of surgical reduction. Figures 19-17 and 19-29 demonstrate the relative placement of implants for each of these methods. The actual surgical techniques for spinous process plating and transilial pinning have been covered.
FRACTURE/LUXATIONS OF THE SACROCOCCYGEAL REGION
Trauma to the sacrococcygeal spine often results in fracture/luxation and is frequently encountered in small animal practice. Patients are typically ambulatory on presentation. Injury to sacral nerve roots can result in loss of voluntary control of the bladder (decreased or absent bladder tone, flaccid urinary sphincter) and loss of anal sphincter reflex. In a recent report of 11 animals presenting with sacrococcygeal fracture/luxation, 6 regained complete fecal and urinary continence while 3 exhibited partial recovery and were manageable with bethanechol chloride and bran.(103) Two animals did not recover. Owners should be cautioned prior to surgical intervention about the possibility and implications of poor neurologic recovery.

The majority of animals with sacrococcygeal fracture/luxations are managed conservatively. If performed, surgical objectives include decompression and visualization for assessment of the gross appearance of the sacral nerve roots. Nerve root injuries can range from mild contusion with eventual functional recovery to complete severance of the affected nerve roots and correspondingly poor prognosis. At the present time, the need for surgery must be based on theoretic or prognostic considerations only, since no controlled studies comparing conservative management with surgical therapy have been performed.

The anatomy of the sacrococcygeal area precludes rigid internal fixation. Surgery is directed at eliminating the potential for further nerve root compression. The sacrococcygeal area is approached dorsally through a midline incision extending from L5 to the level of the fourth or fifth coccygeal vertebra. The multifidus lumborum and sacrococcygeus dorsalis medialis muscles are elevated and retracted laterally from the dorsal spinous processes to reveal the dorsal lamina. A severely displaced fracture/luxation will complicate an otherwise simple approach. Often it is helpful to reduce the sacrococcygeal luxation in a closed fashion prior to beginning the approach. As mentioned, most fracture/luxations in this area are not easily stabilized internally, leaving a choice of tail bracing or tail amputation as alternatives.

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