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Cervical Spine Construct Design

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SUMMARY OF KEY POINTS

- Spine constructs should be patient and pathology specific.
- Most constructs require supplementation with adequate bone grafting to provide long-term stability.
- Cervical spine constructs may be applied in situations of clinical instability, maintenance or correction of alignment, or treatment of refractory pain.
- Most cervical spine constructs are applied in the neutral mode.
- Cervical constructs usually conform to one or more of five basic fixation and load-bearing types: distraction, tension-band, three-point bending, fixed moment arm cantilever beam and nonfixed moment arm cantilever beam.

FUNDAMENTAL CONCEPTS

The successful application of cervical spine instrumentation depends on several factors, including the nature and extent of the disease process, bone quality, and the technical expertise of the surgeon. One of the most crucial, but often overlooked, elements in this process is determined well before the operative procedure is undertaken. This is construct design.

The term *construct* is a neologism that has become entrenched in the spinal literature. For the purpose of this discussion, a construct denotes the aggregate of biologic or nonbiologic materials that are implanted for the purpose of providing stability to an unstable region of the spine. Construct design, then, is the process of contriving such an implant. For the most part, this chapter addresses the design of constructs composed of bone and instrumentation for application in the subaxial cervical spine.

Without a sound construct design strategy, cervical fixation systems are doomed to failure. The meticulous technical application of a poorly conceived construct is a futile exercise, as prone to failure as the correct system improperly applied. Despite its importance, relatively little emphasis has been placed on this element of the procedure. This chapter presents a strategy to aid in the selection of certain instrumentation systems designed for specific clinical problems of cervical spine instability. The specific advantages and shortcomings of each type of construct are also discussed.

Benzel described an excellent method for preoperative mapping of thoracic and lumbar instrumentation procedures, using a "construct blueprint."[1] This approach is practical in this region of the spine, because the choice of implant components that may be applied here is vast. The design of thoracolumbar constructs entails selection of the longitudinal member, cross-fixation mechanism, and implant-bone junction fixators. Each element may be different at various levels of a long construct, adding to the complexity of the system.

Additionally, the modes of construct application that may be used in the thoracolumbar spine are extensive. This refers to the desired forces that are applied by the surgeon at the implant-bone junction. Constructs may be placed in compression, distraction, neutral, translation, flexion, extension, and lateral bending modes.[2] Several modes of application may be required in a single thoracolumbar construct, depending on the structural demands at any given level. A systematic approach to the formulation of an operative plan is essential when designing constructs with this degree of complexity. The construct blueprint is a concise format capable of communicating complicated surgical strategies to all members of the operative team.

The options concerning surgical approaches and types of fixation devices are more limited in the cervical region. The mode of application here is also less variable, because most cervical constructs are applied in the neutral mode. Although this simplifies the cervical construct design scheme, the need for cogent preoperative planning is just as essential. The format used to communicate the operative strategy is less important than the intellectual process of visualizing the biomechanical requirements of a given lesion and formulating an appropriate construct that satisfies these requirements.

The fundamental steps for appropriate construct design are to determine the need for instrumentation, select the construct best suited to solve the instability problem, and ascertain the need for postoperative orthotic stabilization to supplement the implant.

INDICATIONS FOR CERVICAL CONSTRUCT APPLICATION

White and Panjabi outline four general indications for spinal stabilization: (1) to restore clinical stability to a spine in which the structural integrity has been compromised, (2) to maintain alignment after correction of a deformity, (3) to prevent progression of a deformity, and (4) to alleviate pain.[3] Cervical spinal instrumentation may be applied in conjunction with a bone fusion in all of these scenarios. In rare instances, instrumentation may replace bone fusion as the principal means of cervical stabilization.

Optimally, internal fixation provides immediate postoperative stability to the region before the development of osseous fusion. Instrumentation thus protects the neural elements from trauma and the spine from deformity, until the bony fusion matures and can assume this role. Internal fixation also obviates, or at least significantly reduces, the requirement for postoperative external immobilization while the fusion mass heals. This technique improves patient comfort, which encourages accelerated mobilization after surgery. Additionally, this may enhance the probability of attaining successful bone fusion by ensuring compliance with postoperative immobilization.

Internal fixation may allow a reduction in the number of levels that require fusion by adding intrinsic strength and load-sharing properties to the construct. A shorter fusion facilitates the preservation of cervical motion and limits the resultant moment arm created by the fusion mass.

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Clinical Instability

The most frequent indication for cervical instrumentation is instability. To paraphrase an oft-quoted general definition, instability requires the loss of spinal biomechanical integrity such that the spine is unable to prevent initial or additional neurologic deficit, major deformity, or incapacitating pain under physiologic loads.[3] In practice it is essential to determine precisely the nature and extent of spinal instability. The *nature of instability* refers to the status of specific structures that normally confer stability on each motion segment in the cervical region. This concern addresses the competency of the ligamentous structures, bony elements, and annulus fibrosis of the intervertebral disc. Identification of the incompetent elements allows the severity of segmental spinal instability to be estimated. The *extent of instability* denotes the number of unstable motion segments, as well as whether the instability is predominantly ventral, dorsal, or both. Defining these concepts precisely is of fundamental importance, having an impact on the decision to instrument the spine and also dictating the selection of an appropriate construct.

The etiology of spinal instability is important. Symptomatic cervical instability may result from trauma, degenerative disease, neoplasia, or infection. Iatrogenic instability may also occur, particularly after cervical laminectomy for spondylotic disease. Construct design is influenced by the nature of the disease process that produced the instability, as the long-term structural demands placed on a construct are often determined by the progression or remittance of the underlying disease. Posttraumatic instability may demand the least of a construct: short-term immobilization is often all that is required to promote adequate healing. After the injury heals, the load-bearing and load-sharing properties of the construct are no longer required to maintain stability. Spondylotic and iatrogenic instability may require more from a construct, owing to the slowly progressive nature of the process. Instability arising from spinal neoplasia often mandates long-term participation by the instrumentation to maintain structural integrity. Bone fusion may not be attainable because of the rapid progression of disease or adjuvant use of radiation therapy: the instrumented construct must be designed to bear physiologic loads for the remainder of the patient's life.

Maintenance of Alignment

Internal fixation may be indicated to prevent deformity from occurring or to preserve normal alignment after reduction. Unlike thoracolumbar instrumentation, cervical constructs are generally applied in the neutral mode, thus deformity reduction should occur before stabilization. Many constructs designed for use in the thoracolumbar spine can apply significant compressive, distractive, translatory, and rotatory forces to a region of spinal deformity, thus affecting reduction. As a rule, most cervical instrumentation systems cannot apply the magnitude of force required to reduce a deformity and are used predominantly to maintain reduction.

Prevention of spinal deformity may also be accomplished by the timely use of internal fixation. Progressive kyphosis or spondylolisthesis may result from spinal decompression procedures. If individuals at risk for this complication are identified preoperatively, cervical deformity may be preventable. Patients exhibiting a loss of the normal cervical lordotic configuration are prone to develop postlaminectomy kyphosis, which may be avoided by proper internal stabilization at the time of decompression.[4] Similarly, operative resections that compromise principal load-bearing elements may render the spine incompetent to withstand physiologic loads and deformity may be prevented by spinal reconstruction, using bone graft and instrumentation to reconstitute the axial spine.

Pain Management

Spinal stabilization may be indicated to relieve incapacitating pain by reducing motion between spinal segments. This concept has been applied more extensively in the lumbar spine, particularly for treatment of mechanical low back pain arising from spondylolysis and subsequent degenerative spondylolisthesis. Fusion of the cervical spine purely for amelioration of axial pain may benefit certain patients greatly but selecting them is a significant clinical challenge. Such a procedure should be carefully considered and only performed after conservative treatment measures have failed.

CONSTRUCT SELECTION

Cervical constructs should be designed to solve case-specific problems of spinal instability. This requires an understanding of the nature, extent, and causes of instability; load-sharing and load-bearing demands; bone integrity; and biomechanical attributes of various internal fixation systems. Implant cost and ease of application are also important concerns. Constructs may fail as a result of poor design, usually because biomechanical expectations of the implant were unreasonable. Two general rules help guide the selection of a cervical construct and limit unrealistic expectations: (1) the graft and implant must correct the specific preoperative instability, and (2) the long-term success of a cervical construct ultimately relies on the quality of the osseous fusion.

General Considerations

In most cases, cervical constructs are used to maintain clinical stability. This may be accomplished most efficiently by matching the implant with the major site of instability—that is, if the instability is primarily dorsal in location, a dorsal construct should be considered for stabilization. Similarly, ventral instability, created by incompetence of the anterior longitudinal ligament (ALL), vertebral body, or intervertebral disc complex, is most effectively treated by the application of a ventral construct. It is unreasonable to expect that a construct will function with optimal stability when implanted in a biomechanically disadvantageous position.

Internal fixation systems provide immediate postoperative stability to the instrumented region, but they do not provide long-term stability due to the "plastic" properties of bone at the implant-bone interface. As with most biologic materials, bone deforms and reforms when stress is applied.[2] Eventually, even the most rigid construct allows a small degree of motion. Repetitive loading gradually increases the amount of movement and can ultimately lead to implant failure, unless bony fusion occurs. The long-term stability of all constructs is thus dependent on osseous fusion: no internal fixation system currently available can compensate for a poorly designed bone graft.

Cervical spinal implants may be considered as rigid, semirigid, or dynamic.[2] Rigid implants attempt to achieve complete immobilization of the instrumented motion segments. Ventral plate systems, with locking screws and dorsal rod and hook/rod systems, provide rigid fixation. Luque rods and rectangles (Zimmer, Warsaw, IN), secured with segmental sublaminar or facet wires, and most lateral mass plate devices are examples of semirigid cervical implants. Rigid immobilization is potentially detrimental to bone fusion because of stress shielding and stress-reduction osteopenia.[5] This concern has led to the development of dynamic instrumentation, such as

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nonfixed moment arm cantilever beam screw-plate implants and axially dynamic ventral fixators.[6]

Modes of Application

The modes of application available for cervical constructs are more limited than those available for use in other spinal regions. Thoracolumbar implants may be placed in distraction, compression, neutral, translation, flexion, extension, and lateral-bending modes. In contrast, cervical spine constructs are generally applied in the neutral mode. This is not universally true, because certain cervical plate systems and wire constructs may provide a modest degree of compression. Theoretically, cervical rod/screw (or hook) devices can be placed in the compression or distraction modes as well. However, the majority of cervical constructs in clinical use are applied in the neutral mode at the time of surgery. Biomechanical conditions change as the spine is loaded after surgery. Most "neutral" implants must resist axial compression when the upright posture is assumed. These constructs then function in a distraction mode.[2]

Cervical construct designs are also more limited in their mechanism of load bearing than their thoracolumbar counterparts. Generally, cervical constructs conform to one of five fundamental load-bearing types: (1) distraction fixation, (2) tension-band fixation, (3) three-point bending, (4) fixed moment arm cantilever beam, and (5) nonfixed moment arm cantilever beam fixation.[2] Applied moment arm cantilever beam fixation, a technique occasionally applied in the thoracolumbar spine, is not used in the cervical spine. Assigning an implant to one of these fundamental load-bearing types is somewhat artificial, because a given construct may exhibit features of several mechanical types. However, it permits classification of implants by their principal biomechanical attributes.

Simple Distraction

Simple distraction fixation occurs when a distraction force is applied by a cervical construct, usually from a ventral, interbody location. Interbody strut grafts are the most common examples of this type of fixation. These devices principally resist axial loads. Dorsally applied interfacet distraction is seldom used because it may cause kyphosis when improperly applied. However, this method has been shown to be a safe and useful adjunct to increase foraminal area.[7]

Tension-Band Fixation

Tension-band fixation is accomplished by any device that reconstitutes the ventral or dorsal tension band, thereby preventing distraction, and also possibly angulation, in the opposite direction. This type of fixation may be applied dorsally with interspinous wires or cables, sublaminar wires or cables, facet wires or cables, interlaminar clamps, or lateral mass screws and rods. These dorsal devices resist flexion most efficiently, because the flexion moment is coupled with dorsal distraction. Ventral tension-band fixation is accomplished principally with ventral cervical plate systems. These implants reconstitute the ventral tension band, thereby resisting ventral distraction and providing sound biomechanical stabilization of extension injuries.[8]

Three-Point Bending

Three-point bending fixation occurs when forces are applied to the spine at three or more sites along the length of the construct.[2] Dorsally directed forces are applied at the rostral and caudal ends of the construct. An equal but opposite ventrally directed force is applied at the fulcrum, usually in the center of the construct. Three-point bending instrumentation is applied dorsally in the cervical spine so to create lordosis and must fixate multiple motion segments. This type of fixation has been historically accomplished with Luque rods/rectangles secured with sublaminar wires or cables, lateral mass rib-wire constructs and hook/rod implants but is today more usually accomplished with lateral mass screws and rods.

Cantilever Beam Fixation

A cantilever is formed by a projecting beam supported at one end only. When the cantilever is rigidly attached to the supporting longitudinal member, a fixed moment arm cantilever beam is created. This variety of load bearing is accomplished by ventral cervical plate systems secured with locking screws and rigid lateral mass screw/rod instrumentation. A fixed moment arm cantilever beam device contributes some axial load-sharing properties to the construct. Nonfixed moment arm cantilever beam fixation employs a dynamic attachment of the cantilever to the longitudinal member: axially dynamic ventral fixators are the most common example of this type of load bearing today.

The classification of spinal implants by mechanism of load bearing is somewhat artificial. In practice, a single implant may function by using several of the fundamental load-bearing mechanisms simultaneously. For example, the lateral mass screw/rod construct is capable of stabilization by three such mechanisms: dorsal tension band, three-point bending, and fixed moment arm cantilever beam fixation may all be accomplished.

Construct Materials

A variety of biologic and prosthetic materials have been used for cervical spine stabilization. Most constructs are composed of a bone graft, coupled with a metal prosthesis. Occasionally, bone or metal components may be supplemented or replaced by methyl methacrylate or plastic.

Bone Grafts

Autograft and allograft bone have both been used extensively in spinal stabilization. High fusion rates are reported using either autograft or allograft but may be marginally higher with autograft. The use of autograft bone eliminates the very small concern of infectious disease transmission that may be associated with allograft bone, including human immunodeficiency virus (HIV) and hepatitis virus transmission, but carries the risk of donor-site morbidity.[9-11]

The iliac crest provides a versatile and abundant source of bone graft material for incorporation into cervical spine constructs. Favorable attributes of this type of graft include ease of procurement in the supine and prone positions, strength, and relative expendability of the donor site. The tricortical structure of the iliac crest is responsible for much of the strength inherent in this graft, thereby providing excellent axial load-bearing capability. The abundant cancellous bone provides ample substrate for osseous remodeling. Although all commonly used configurations of iliac crest grafts can sustain high compressive loads, the Smith-Robinson type graft is probably superior to other styles of grafts in this respect. The principal disadvantage associated with iliac crest harvest is donor site morbidity, which may be substantial. Complications include pain, wound hematoma, infection, meralgia paresthetica, hip dislocation, and fracture of the anterior superior iliac spine.[8]

Fibula is another commonly used graft material. It is particularly well suited for multilevel ventral reconstruction

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procedures, because the thick cortical bone in this graft resists high axial compressive loads. The relatively small amount of cancellous bone present in the fibula graft may delay bone remodeling, however. This may be partially overcome by packing additional cancellous bone in the center of the graft, as well as surrounding the outer cortical surface with the cancellous bone. Donor site morbidity arising from graft harvest may be significant, because one sixth of body weight is borne by the fibula so it is basically employed today from cadaver donors, particularly for reconstruction after anterior corpectomy due to its shape.

Rib grafts have also been used, particularly with dorsal cervical constructs. The native configuration of rib is advantageous because it conforms well to the cervical lordotic curve. There is minimal morbidity in harvesting rib as compared to iliac crest, rendering it an excellent option for posterior reconstructions.[8]

Implants

Currently most spinal implants are fashioned from metal. Stainless steel was once used extensively for the manufacture of wires, cables, plates, screws, hooks, and rods used in spinal constructs, but its use has been largely discontinued due to the advent of newer titanium alloys. These alloys possess a relatively high tensile strength while retaining a reasonable degree of malleability, often required to tailor a component to anatomic specification, and are biocompatible. These alloys further facilitate postoperative imaging because they do not generate the significant artifact stainless steel does on magnetic resonance imaging (MRI) and computed tomographic (CT) imaging. Other synthetic materials have substituted titanium alloys in cervical constructs, particularly interbody cages. The most widely used are polyetheretherketone (PEEK) and carbon fiber cages. Their most striking advantage is relative radiolucency, therefore enabling good postoperative imaging and, particularly, assessment of fusion. Better fusion rates reported in the literature with PEEK interbody spacers may in fact correspond to better visualization in this patient population.[11,12]

Regardless of the material used, compatibility of the implanted components is essential. All metal implants should be made of the same material. This eliminates the theoretic possibility of internal current generation that may cause corrosion. The size of implanted components should also be compatible. Fixators at the implant-bone junction should be of appropriate diameter, length, and configuration to match the longitudinal member.

The integrity of the patient's native bone is an important factor. Bone quality can have an impact on construct selection, the biomechanical stability of a construct, and the need for postoperative external immobilization. Osteoporosis is detrimental to all forms of spinal fixation. It influences systems that rely on screw fixation most substantially. Hooks and sublaminar wires are less prone to pullout than screws, and thus they may be more suited for use in the osteoporotic patient. Poor bone quality may necessitate incorporation of additional levels into a construct to promote load sharing and enhance stability but may be difficult to assess. A general impression of bone mineralization may be gleaned from plain cervical radiographs. Dual-energy x-ray absorptiometry and quantitative CT provide an objective determination of bone mineral density. The clinical use of this technology is limited by the lack of cervical spine standards available for comparison. Also, the influence of bone mineral density on screw fixation biomechanics is poorly understood. Currently it is not possible to predict the holding strength of fixators at the implant-bone junction from preoperative studies.

Construct Application

Cervical spine integrity may be restored by either ventral or dorsal stabilization techniques. The application of both may be indicated in cases of severe instability creating a "360 degree" construct. The rationale for selecting one approach over another is case dependent and relies on the degree and extent of instability. If the site of major instability is ventral, a ventral construct should be created to restore structural integrity to the ventral spine. Dorsal instability is treated most effectively through dorsal stabilization. This general rule is valid for all causes of cervical instability. The underlying disease process does influence the selection of specific construct components and the method by which they are applied.

Neural compression often accompanies cervical instability and must be alleviated before stabilization. Neurologic deficit may result from direct neural compression by the disease process itself or by attendant spinal instability. The requirements of neural element decompression in the cervical spine influence the approach that is selected for stabilization; as a general rule, the approach should match the site of worst compression (anterior or posterior), but several exceptions exist. For example, extensive ossification of the posterior longitudinal ligament (OPLL) may result in excessive morbidity when approached anteriorly and thus is frequently treated through an indirect, posterior approach. Posterior decompression, however, is ineffective in the setting of cervical kyphosis and its application may necessitate correction of the deformity either in the same setting or through a separate anterior approach.

The surgeon must be wary and avoid exacerbation of neural compromise by the process of spinal stabilization. For example, dorsal tension-band fixation may increase ventral neural compression resulting from traumatic intervertebral disc herniation or neoplastic disease. This may produce additional neurologic deficit. Constructs must be designed with consideration for the structural alterations that they may induce and the effect that this may have on the neural elements. If this is not appreciated, disastrous consequences may follow.

VENTRAL CONSTRUCTS

Ventral cervical spine constructs are designed to restore stability to the ventral spine when the osseous or ligamentous structures are incompetent. Intervertebral strut grafts without instrumentation have been used since the 1970s to reconstitute the ventral load-bearing column of the cervical spine. Polymethylmethacrylate has been historically used as an alternative to bony fusion in this region but is now restricted to few cases of neoplastic disease with limited life expectancy. A variety of cervical constructs may be applied via the ventral approach. The following review is not exhaustive but represents the majority of techniques currently used for ventral cervical stabilization.

Interbody Strut Graft

A simple, short strut graft is frequently employed following an anterior cervical discectomy but may also be a longer graft for vertebral body replacement after corpectomy for trauma, neoplasia, and spondylotic disease. Ventral strut grafts function predominantly in the simple distraction mode, reconstituting the ventral load-bearing column of the cervical spine. This construct offers excellent resistance to axial compressive loads (Fig. 57-1). It also imparts some stability in flexion, extension, axial rotation, and lateral bending.[13] In most cases, however, immediate postoperative stability is not provided with a simple strut graft.

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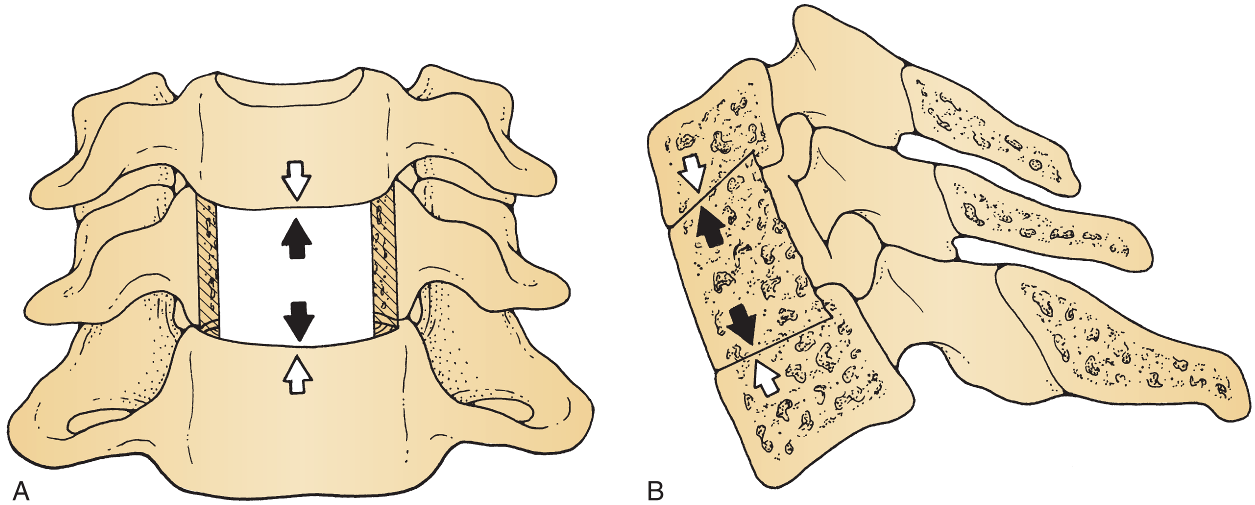

Figure 57-1. Coronal (**A**) and lateral (**B**) views of an osseous strut graft. This construct functions in a simple distraction mode *(solid arrows)*, providing resistance to axial compression *(open arrows)*.

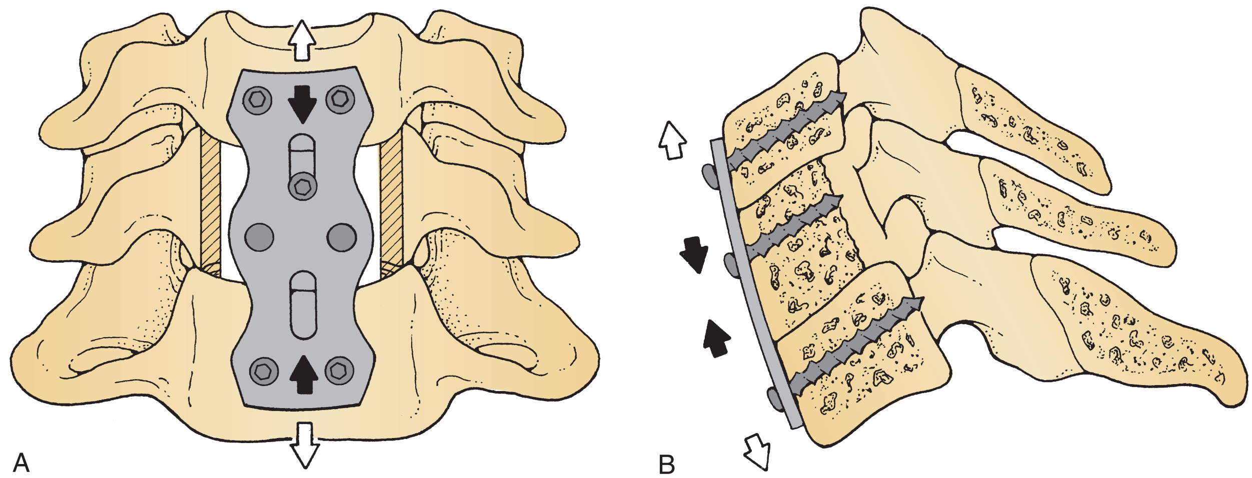

Figure 57-2. Coronal (**A**) and lateral (**B**) views of a ventral cervical plate (bicortical, unlocked) construct. The plate/screw device reconstitutes the ventral tension band *(solid arrows)*, thereby resisting ventral distraction and extension *(open arrows).* Axial compressive forces *(not shown)* are resisted by the strut graft.

Some means of fixation, whether external or internal, is usually required to provide temporary stability while awaiting osseous fusion. The extent of supplemental fixation is dictated by the degree of instability that remains after placement of the bone graft. The instability created by a single-level ventral cervical discectomy may be managed adequately with interbody strut graft placement and immobilization in a cervical collar.[11] More significant instability requires more rigid fixation while the fusion matures such as that ensuing from a two-level decompression, through either discectomies or a corpectomy. In the setting of multilevel corpectomy, there is some evidence to suggest increased fusion rates and less kyphosis when supplemented with posterior instrumentation, but this point is still under debate.[14,15]

Cervical cages are another means of stabilizing the anterior column. These devices may be made of titanium, carbon, or other materials. Threaded cages appear to provide greater initial stiffness than do nonthreaded devices. This fact, however, may be misleading, as subsequent subsidence may lead to a subsequent decrease in stiffness.

Ventral Cervical Plate and Screw Constructs

Ventral cervical plate and screw constructs were developed to provide immediate internal stability before osseous integration of a strut graft, often eliminating the need for postoperative external bracing. All ventral plate constructs reconstitute the ventral tension band, thereby stabilizing most significantly in extension. Some of these devices, particularly rigid plates with fixed-angle screws, also provide fixed moment arm cantilever beam fixation, thereby sharing some of the axial load with the strut graft. Plating systems that use nonlocking, variable-angle screws are more dynamic implants and provide less axial load sharing. These devices act as nonfixed moment arm cantilever beam fixators, in addition to their tension-band attributes (Fig. 57-2). Dynamic implants such as these also allow for the graft to be exposed to continuous axial loading, which may facilitate bone fusion.

Biomechanical studies have demonstrated that ventral plates can restore stability to the injured spine in essentially all motion planes, although this is most significant in flexion

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and extension.[16] An interbody bone graft must supplement the instrumentation to effectively stabilize an injured motion segment. The load-bearing capacities of ventral cervical plates are temporary, so all plated segments must be fused to achieve long-term stability.

Ventral cervical plates are affixed with screws at the implant-bone junction, which can be placed as uni- or bicortical fixation. Bicortical screw purchase confers greater holding strength to the construct.[17] Placement of bicortical screws is more perilous than that of unicortical screws, and fluoroscopy is utilized to avoid traumatizing the spinal cord: unicortical screws may be applied with less hazardous results.

Indications for ventral cervical plating are extensive. As a general rule, traumatic, unstable injuries involving the vertebral body or intervertebral disc are managed most efficiently by ventral stabilization. This is particularly important when there is compromise of the ventral spinal canal by bone fragments or herniated intervertebral disc material. Cervical burst fractures may require ventral decompression and internal fixation. A strut graft for vertebral body replacement and a ventral plate for immediate internal stability are appropriate construct designs for this indication. For most traumatic and neoplastic indications, ventral plates should be applied to intact vertebral bodies above and below the involved levels, spanning the instability.

Other traumatic lesions may be stabilized ventrally. Irreducible facet dislocations are generally approached dorsally. However, when facet dislocation is complicated by concomitant disc herniation, decompression and reduction may be undertaken via a ventral approach. Stabilization is then accomplished with an interbody bone graft and a ventral plate. Neural decompression must precede reduction of the spinal deformity, thereby minimizing the risk of producing or exacerbating a neurologic deficit.

Cervical spondylotic disease may also be treated by ventral decompression and stabilization, using ventral plates. Kyphotic deformities, regardless of etiology, should be approached ventrally. Corpectomy, strut grafting, and ventral plate stabilization should be considered first-line therapies for this type of spinal deformity. As with all devices that use screw fixation, ventral plating systems perform poorly in osteoporotic bone.

DORSAL CONSTRUCTS

Dorsal constructs are designed to restore stability to the spine when the dorsal osseous or ligamentous structures are incompetent. Several constructs may be applied via this approach. Basic wiring techniques, incorporating the spinous processes, laminae, or articular facets with or without a bone graft, are time-tested methods used to treat spinal instability. Luque rods and rectangles have also been used with success in this region. Lateral mass-based systems have gained widespread acceptance for dorsal cervical stabilization. Hook/rod devices and interlaminar clamps have also been used for specific applications in the posterior cervical spine.

Wire Constructs

Dorsal stabilization with wire or braided cables usually entails incorporation of the spinous processes or articular facets, with or without bone autograft. These constructs function primarily by reconstituting the dorsal tension band (Fig. 57-3). Dorsal wire constructs provide some stability in flexion, minimal stability in extension, and add little to rotatory or translatory stability. If translational instability exists, dorsal tension-band fixation implants may be inadequate to prevent the "parallelogram effect," resulting in translatory displacement and further spinal deformity. Wiring is an inexpensive, rapid, and relatively safe method to restore the posterior tension band but is usually insufficient to restore stability, requiring supplemental fixation.

Interlaminar Clamps

The dorsal tension band may also be re-created by application of interlaminar clamps. These devices are used rarely, because they are somewhat unwieldy to apply and may be hazardous. These clamps function by reconstituting the dorsal tension band and may be adequate to restrict flexion. No stability is

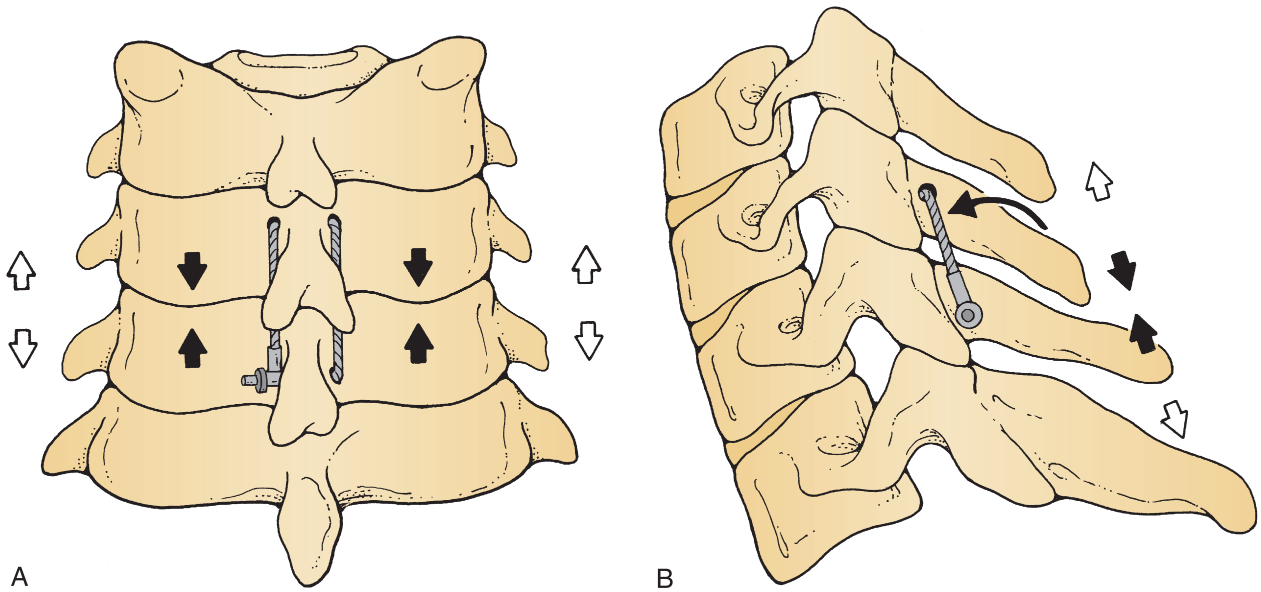

Figure 57-3. Coronal (**A**) and lateral (**B**) views of interspinous cable fixation. This construct reconstitutes the dorsal tension band *(solid arrows)* and resists dorsal distraction *(open arrows)*. As flexion and dorsal distraction are coupled, the flexion moment *(curved arrow)* is resisted across the fixed level.

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provided in extension or axial rotation. Extension is prevented by placing the bone graft between the spinous processes, and this was once a common method to achieve C1-2 fusion (modified Gallie fusion). Interlaminar clamps require intact laminae at the levels to be instrumented.

Luque Rods and Rectangles

Originally used for thoracolumbar instability, Luque rods and rectangles may also be incorporated into dorsal cervical constructs. These devices are usually applied over multiple spinal segments and secured with sublaminar or facet wires. Alternatively, braided cables may be used to affix the construct at the implant-bone junction. They act principally as rigid implants, reconstructing the dorsal tension band. Additionally, they provide a significant degree of three-point bending fixation (Fig. 57-4). These implants stabilize in flexion, extension, and lateral bending modes.

The use of a rectangle rather than two L rods is biomechanically advantageous, because of the strong cross-fixation provided by the rectangle configuration. Torsional stability is enhanced by this design, and "telescoping" is less likely. These concerns may be partially alleviated by cross-fixation of L rod constructs. However, they may be challenging to apply and offer less fixation than lateral mass-based systems and thus are seen today mostly when removing older systems or addressing adjacent level degeneration.

Lateral Mass Plate/Rod Fixation

Dorsal cervical stabilization has been revolutionized by the development of lateral mass-based systems. These devices provide a high degree of immediate internal stability, often eliminating the need for postoperative external immobilization or bracing. Lateral mass plates are dynamic implants and behave primarily as nonfixed moment arm cantilever beam fixators. They also provide some dorsal tension-band fixation (Fig. 57-5). Biomechanical studies have demonstrated the ability of these devices to restore stiffness to the injured spine in flexion, extension, and torsion. Similar to other constructs that restore the dorsal tension band, lateral mass plates are probably weakest in extension.[18]

Lateral mass screws and rods may be used to treat instability from C2 to T1, but modern systems allow for combination with occiput/C1 or thoracic pedicle-based fixation. Dorsal ligamentous injury and irreducible unilateral or bilateral facet dislocations may be stabilized effectively with this type of construct after reduction of malalignment. In these cases, instrumentation across the affected segment alone is usually adequate to restore stability. Multiple segments of instability

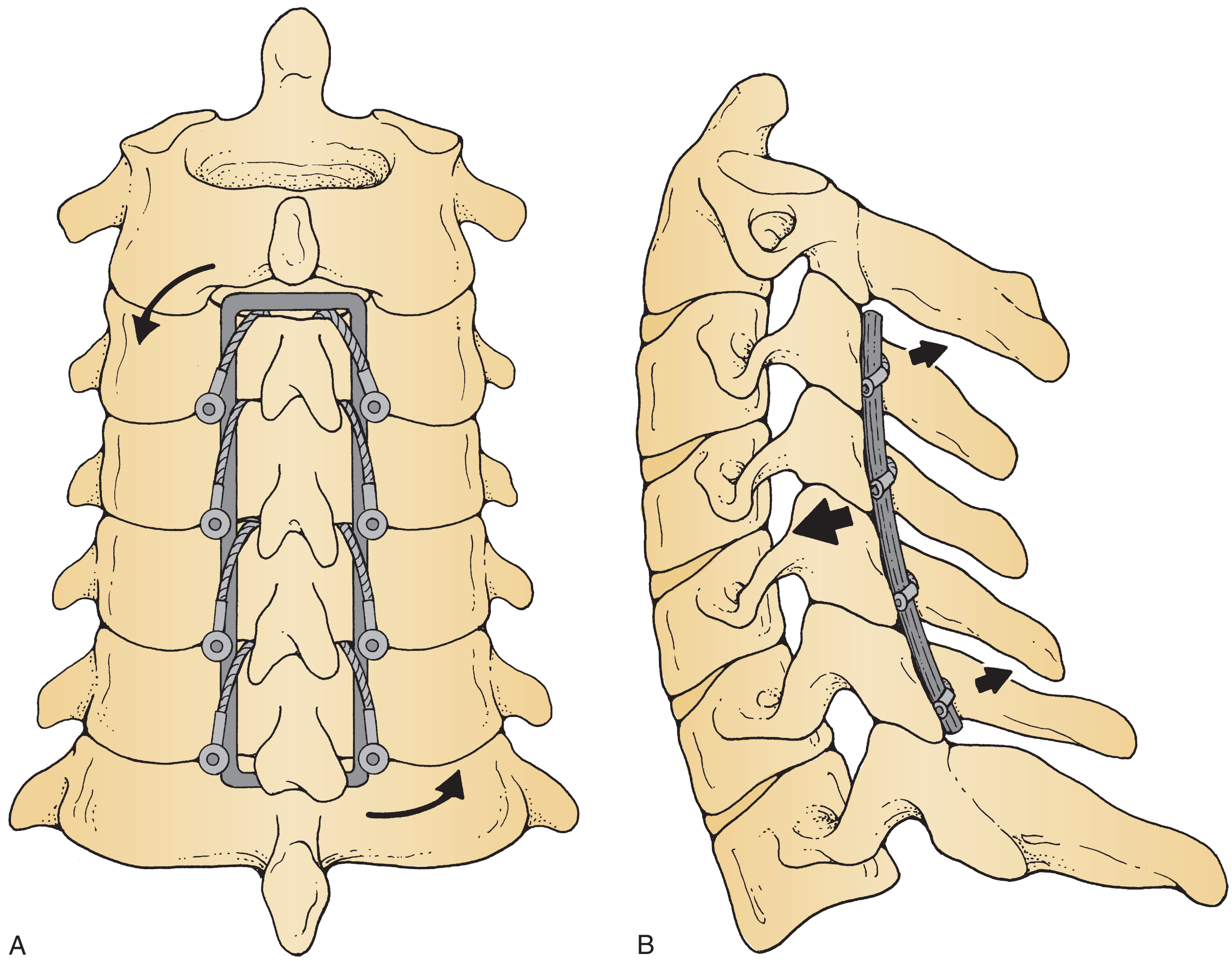

Figure 57-4. Coronal (**A**) and lateral (**B**) views of a Luque rectangle construct. This device provides three-point bending fixation. Dorsally directed forces are applied at both ends of the construct, with an equal but opposite force applied at the fulcrum *(straight arrows)*. Torsional stability *(curved arrows)* is imparted by the strong cross-fixation of the rectangle. Distraction and flexion are also resisted, as this device reconstructs the dorsal tension band. Although the illustration depicts fixation with sublaminar cables, the authors do not recommend sublaminar cable passage in the midcervical spine.

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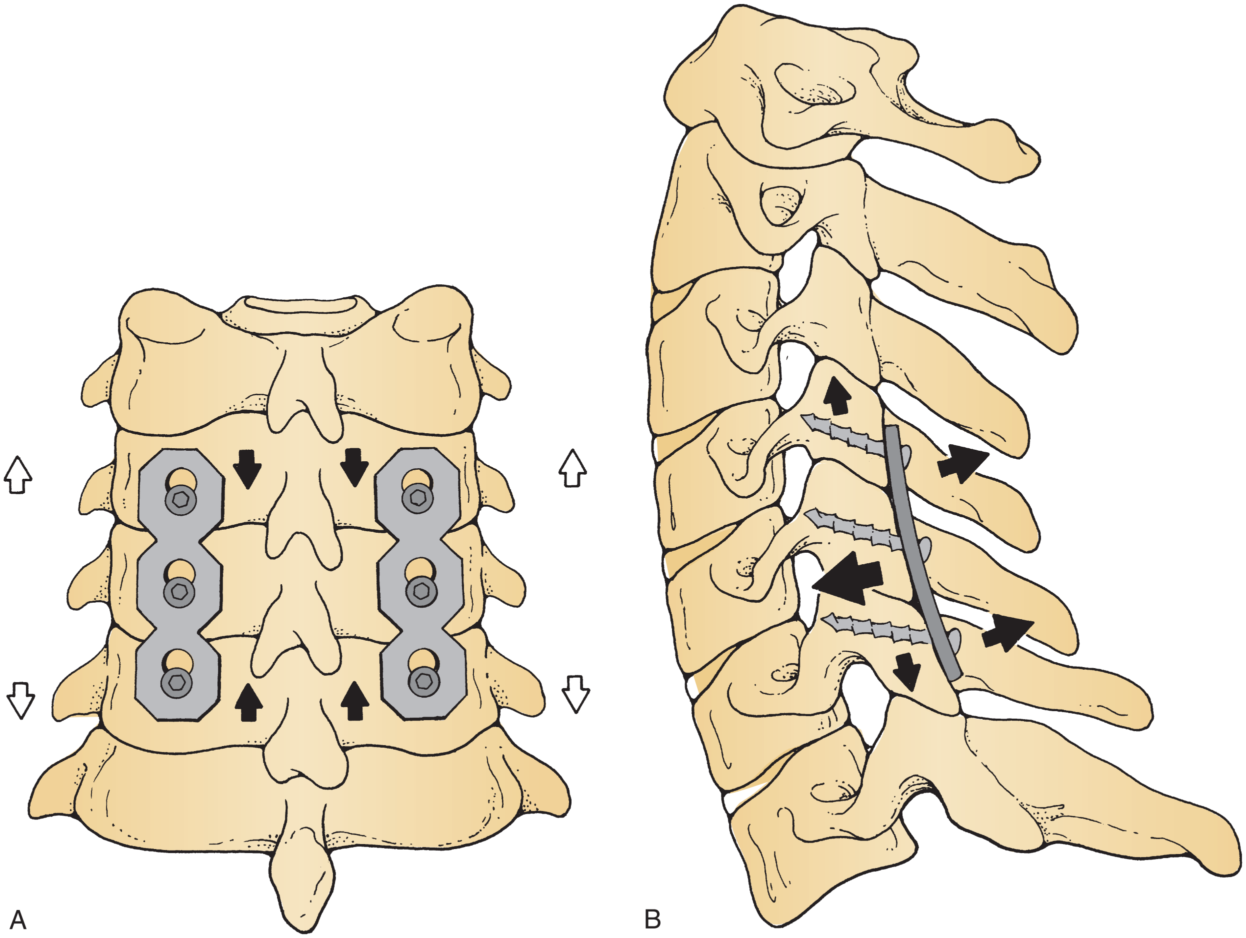

Figure 57-5. Coronal (**A**) and) lateral (**B**) views of a lateral mass plate construct. This device provides stabilization in all motion planes, using tension band (*solid vertical arrows* in **A**), three-point bending (*arrows* in **B**), and cantilever beam fixation (*small arrows* in **B**).

may also mandate instrumentation of additional levels to achieve an adequate biomechanical advantage.

Fractures of the articular facet, pedicle, or lamina at a given level usually require a multilevel construct to restore stability. An intact level above and below the site of injury should be instrumented. Instability arising from vertebral body fractures has been successfully treated with lateral mass systems, usually incorporating multiple levels into the construct. This should only be attempted when the articular facets at that level are intact, because they must contribute to axial load bearing in this situation. In most cases of vertebral body injury, however, and especially if there is ventral canal compromise, a ventral approach is indicated. Once again, the general rule in neoplastic or traumatic disease is that instrumentation should be placed in bone free of disease.

Instability created by degenerative disease may also be treated with lateral mass plates. This is particularly effective when the dorsal load-bearing elements are incompetent. Additionally, these devices may be applied at the time of laminectomy to prevent progressive kyphotic deformity in patients who are deemed to be at risk. This is more effective than attempting to treat an established kyphotic deformity with dorsal instrumentation, because lateral masses are at a mechanical disadvantage in the latter, usually requiring an anterior-posterior combined procedure. Incorporating bone graft into the construct augments long-term structural stability. This may be accomplished by denuding the articular processes at the unstable level(s) and packing cancellous bone graft into the joint space.[7] Often, adequate material for bone autograft may be obtained from adjacent spinous processes or from bone removed during decompression.

Advantages of lateral mass plates over other dorsal construct designs include superior biomechanical stability in essentially all planes and applicability to a variety of clinical settings. These devices may be applied in the presence of extensive laminectomies or dorsal element fracture. They provide immediate postoperative stability without passage of sublaminar wires. Their installation may prolong the operative procedure somewhat and requires special equipment and technical expertise. Use of these devices should be avoided in patients with inferior bone quality, because screw fixation systems perform poorly in this setting. If screws are used in this situation, postoperative immobilization with an appropriate orthosis should be considered.

Even though lateral mass screw/plate systems can be applied to treat instability arising from several etiologies, the plate can be bent only on the sagittal plane. There is no possibility of contouring it in the coronal plane whatsoever, and therefore it may be particularly difficult to apply in some degenerative conditions or when anatomic peculiarities such as hemivertebrae provide for misaligned screw heads. To address this condition, polyaxial screw/rod constructs were developed in the 1990s and have today largely substituted most screw/plate designs. They provide the same biomechanical stability with much greater ease of application.

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Cervical pedicle screws have also been shown to provide appropriate dorsal stabilization for the cervical spine.[2] However, cervical pedicle screws are significantly more difficult to place than lateral mass screws, and they carry a higher risk of injury to the nerve root and the vertebral artery. Lateral mass screws are probably equally effective in biomechanical stabilization and safer in most situations.

Anterior-Posterior Constructs

Occasionally, cervical spinal instability will be so severe that it warrants both ventral and dorsal stabilization, creating a "360-degree" construct. This approach is usually reserved for situations of ventral and dorsal instability. To justify a 360-degree procedure, there must be a reasonable concern that instability will persist or recur, despite stabilization via an isolated ventral or dorsal approach. This clinical scenario may be encountered in cases of advanced malignancy, extreme traumatic injuries, extensive degenerative disease, or postlaminectomy kyphosis, for example. When an osseous strut graft is internally stabilized with a ventral plate, only two motion segments are actually fixed. The intervening motion segments may require dorsal fixation to provide optimal stability to the construct in cases of extreme instability or to correct the underlying deformity.

Ventral plating and lateral mass-based systems may be applied concurrently, in conjunction with appropriate bone grafting (Fig. 57-6). In most cases these devices should confer an optimal biomechanical advantage to the construct, providing immediate internal stability in all motion planes. Other constructs may be devised if screw fixation is contraindicated because of poor bone quality. These situations are rare and necessitate individualized management. However, fundamental construct design concepts should guide the selection and application of hardware systems, just as in less complex problems of instability.

Figure 57-6. Lateral cervical radiograph showing 360-degree reconstruction.

ECONOMIC CONSIDERATIONS

Historically, economic considerations have not been major determinants in the process of construct design. This is no longer true because rising health care costs and declining reimbursement mandate some fiscal responsibility. Material costs represent only a fraction of the expense accrued with spinal instrumentation. Surgeons' fees, operative time, anesthesia support, and fluoroscopy costs (if required) all reflect the complexity of a stabilization procedure. Thousands of dollars may be expended to apply a single construct. With this in mind, it is financially irresponsible to implant an elaborate, costly system when a less expensive alternative could suffice. However, the structural integrity of a construct should not be compromised for purely economic concerns. The spine surgeon must use restraint in the construct design process, minimizing expenses when possible.

SUPPLEMENTARY EXTERNAL IMMOBILIZATION

The need for postoperative external immobilization may be reduced or eliminated when internal fixation provides immediate stability to a construct. Orthoses are selected in accordance with the nature and extent of preoperative instability, quality of the construct, cause of instability, and extent of residual disease. Young patients with isolated dorsal instability can be managed in a soft cervical collar for 4 weeks after most instrumentation procedures. Patients with more severe instability or residual disease require more aggressive postoperative bracing. A hard cervical collar is probably adequate in most cases. Those with osteoporosis, severe preoperative instability, craniocervical pathology, or biomechanically inferior constructs that do not provide sufficient immediate internal stability require a postoperative halo vest or Minerva immobilization.[16] Regardless of the bracing method, all patients should be assessed often with serial examinations and radiographs until an osseous fusion is attained.

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