Spinal Fixation

Part 1. Principles, Basic Hardware, and Fixation Techniques for the Cervical Spine[1]

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Spinal fixation devices provide stability and restore anatomic alignment in the treatment of fractures, degenerative disease, infection, and tumors and correct congenital deformities such as those seen in scoliosis. The devices provide immediate stability but are not strong enough to withstand prolonged stress and eventually fail, in most cases, if bone fusion does not occur. Bone graft material is often used to promote fusion and to replace bone after resection. Internal fixation is used to maintain position and alignment and to prevent motion as the spine fuses. Plates and rods are attached to the vertebral body or posterior elements with wire, screws, and hooks. Screws and wire can also be used alone as a means of fixation. Surgical techniques and instrumentation have advanced in recent years, and radiologists are exposed to a myriad of devices. They need to be able to identify the various plates, screws, wiring techniques, and grafts used most commonly and to understand their function in the cervical spine for fusions and treatment of fractures and degenerative disease.

■ INTRODUCTION

Radiologists routinely encounter radiographs of patients who have had spinal surgery. Sometimes the evidence is as subtle as a laminotomy, and other times major instrumentation remains as the result of surgical fixation for segmental fusions. There are a great number of fixation devices that have been employed by orthopedists and neurosurgeons over the years, as new techniques and equipment have been devised. It is important for radiologists to be able not only to recognize these implants, but to understand their intended purpose and be familiar with the biomechanical principles by which they function. Only then can the radiologist adequately evaluate the postoperative spine and be prepared to recognize evolving complications.

Abbreviation: AP = anteroposterior

Index terms: Spine, developmental defect, 31.14, 31.861 • Spine, diseases, 31.78 • Spine, fractures, 31.41 • Spine, infection, 31.20 • Spine, injuries, 31.42 • Spine, primary neoplasms, 31.32, 31.36 • Spine, secondary neoplasms, 31.33, 31.37 • Spine, surgery, 31.45

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Spinal fixation is used for stabilization of the spine after fracture, for reconstruction after resection of tumors or destruction from infection, and for treatment of congenital and acquired spinal diseases, such as scoliosis, spondylolisthesis, spinal stenosis, disk disease, and inflammatory and degenerative arthritis. Currently, the most common use of internal spinal fixation is to reduce the rate of pseudarthrosis after fusion and to restore anatomic vertebral alignment after trauma (1). Fusion is nearly always performed in conjunction with internal fixation. Metallic devices are subject to fatigue failure; they are unable to withstand the stresses of weight bearing, flexion, extension, and lateral bending for prolonged periods and eventually loosen or break if bone fusion does not occur.

The primary nontraumatic indications for stabilization surgery are scoliosis, degenerative instability, and neural decompression. However, surgical intervention is only indicated in a carefully selected percentage of these cases. For this reason, orthopedists and neurosurgeons manage a majority of these cases nonoperatively. Exercise has been successfully promoted as a means for the prevention and treatment of back pain. Advances in imaging have generally eliminated exploratory spinal surgery, and, by knowing exactly what to expect, detailed surgical techniques are now planned in advance.

The purpose of this article is to familiarize radiologists with the basic internal fixation devices used in the spine, their intended function, and the biomechanical principles that direct their use. The techniques and instrumentation employed differ considerably, but, for convenience, they can be divided into four categories according to anatomic location: (*a*) the occipitocervical junction, (*b*) the lower cervical spine, (*c*) the thoracic and lumbar spine, and (*d*) the lumbosacral spine. In addition, most fixation techniques can be classified as anterior or posterior and by the site of attachment to the spine (lamina, pedicles, or vertebral body). In this article, we discuss the basic principles of spinal fixation, as well as the specific techniques and hardware used in the cervical spine (Table). The hardware and techniques used in the thoracic, lumbar, and lumbosacral spine and the complications of spinal instrumentation will be discussed and illustrated in future articles.

■ BASIC PRINCIPLES

Surgical implants are used in spinal reconstruction to (*a*) obtain anatomic reduction, (*b*) maintain stabilization, and (*c*) act as a replacement. In the spine, the most common mechanism for reduction is to align the fragments under tension along the line of intact ligaments. Ligamentous integrity can be predicted preoperatively from the fracture pattern or from the effect of traction on spinal alignment. Implant systems incorporating rods are well suited for reduction. The vertebrae that are attached to the rod can be distracted and aligned, and pathologic angular deformities can be corrected.

The most common use of spinal instrumentation is to provide stabilization to promote bone fusion. Fusion must occur to prevent implant failure or loosening. The instrumentation is no longer needed after fusion but is generally left in place indefinitely because of the risks associated with repeated surgery. Indications for removal, if fusion has been accomplished, include infection and pain.

Replacement in the spine refers to reconstruction of a defect after vertebral body removal (sometimes referred to as corpectomy) or compression fracture. Vertebral body removal results in axial instability, and implants function primarily to prevent collapse. Vertebral body replacements include structural bone grafts, bone cement, and titanium cages. Disk replacements are not currently available commercially.

Stability in the spine refers to the ability to resist deformation under physiologic forces. Spinal stability prevents displacement, deformity, and neurologic compromise. The spine can become unstable over the short term or long term when exposed to external forces. Acute instability results from ligamentous failure or fracture of the vertebral body or facets. Radiographic evidence of acute instability includes translations greater than 3.5 mm and single-level angulation greater than 11° on dynamic images. Chronic instability can result from disk incompetency, accompanied by degenerative changes in the facets. Significant clinical symptoms can develop if progressive scoliosis or vertebral body slippage occurs. Clinical evidence of painful instability can be obtained empirically by immobilizing the patient in an appropriate orthosis.

Internal fixation of the spine was first attempted in the late 19th century (1). Before the development of stainless steel in the 1930s, material used for implants was subop-

Instrumentation and Techniques Used in the Cervical Spine

- Traction
  - Gardner-Wells traction tongs
- Distraction
  - Halo collars
- Screws
  - Cortical
  - Cancellous
  - Cannulated
  - Knoringer
- Wire and cable
  - Wire
  - Songer cables
- Plates
  - Occipitocervical plate
  - Caspar plate
  - H plate
  - Morscher cervical locking plate
  - Haid plate
  - Tubular plate
  - Malleable reconstruction plate
  - Hook plate
- Replacement
  - Methylmethacrylate
  - Structural bone grafts
- Miscellaneous
  - Halifax clamps
  - Titanium cages
- Techniques for fusion
  - Anterior cervical
  - Brooks
  - Rogers
  - Cloward
  - Yale

timal and the devices often had to be removed because of failure or complication (2). Internal spinal fixation has undergone substantial development during this century. Screws placed through the facet joints to produce stabilization after fusion is a concept that was reported in the 1940s by King (3). Distraction rods (Knodt rods) and plates bolted to the spinous process with accompanying bone graft were developed and described in the 1950s (4,5), Harrington rods in the early 1960s (6,7), pedicle screws and plates in the 1960s (2), Luque rods and sublaminar wire in the 1970s (8,9), and intrapedicle screws attached to rods in the early 1980s (2).

■ SPINAL FUSION

Successful correction or repair of a spinal deformity often necessitates spinal fusion. The instrumentation provides immediate stability and serves to maintain the correction only until bone fusion occurs. Internal fixation devices also increase the rate of solid arthrodesis (1). Without successful arthrodesis, the mechanical devices used in the spine eventually fail because of repeated stresses. The first successful spinal fusion was reported in 1911 (1,10,11), and spinal instrumentation was originally developed to reduce the rate of pseudarthrosis after spinal fusion (1). Bone grafting greatly increases the success of spinal fusion. The use of iliac bone as an autologous donor site was reported in 1933 (12). The transverse processes were not routinely incorporated into the fusion mass until the late 1960s (2).

Unlike management of other joints in the body, replacement arthroplasty of the spine is not an option at the present time, and spinal fusion is often performed for instability (1). In some cases, such as single-level fusions after diskectomy, internal fixation is not used and fusion still occurs. As the complexity and extent of the spinal surgery increases, so does the risk of pseudarthrosis. In some cases, external braces (orthoses) are worn to minimize motion and maintain stability during the healing phase. External braces are far less immobilizing than internal fixation. Any motion at the intended level of fusion during the healing phase increases the risk of pseudarthrosis.

Anterior interbody spinal fusion was first reported in 1933 (13) and refers to fusion of the vertebral body. This is accomplished by excising the intervertebral disk or removing a complete vertebral body and replacing it with bone graft material such as a piece of rib, iliac crest, fibula, or tibia. Supplemental material from the iliac crest can also be ground or milled to produce a bone graft paste. Anterior fusions are indicated in cases in which bone fragments or disk material encroach on the spinal canal, necessitating decompression. Successful anterior fusion often requires posterior stability.

Posterior fusion involves fusion of the posterior elements. This is accomplished with a posterior approach and is performed to maintain correction of scoliosis, treat unstable fractures involving the posterior elements, and correct instability resulting from multiple-level laminectomies. A posterior fusion can include bone graft material placed along the transverse processes, facets, or lamina and may extend up to and include the spinous processes. Again, internal fixation is often used to maintain stability during bone fusion and reduce the risk of pseudarthrosis. Posterior onlay fusion, first reported in 1944 by Briggs and Milligan (14), has a lower rate of pseudarthrosis than anterior fusions of the lumbar spine.

■ TRAUMA

Injuries of the spine can result from one of five mechanisms: flexion, extension, rotation, lateral bending, or axial compression. Fractures of the thoracic and lumbar spine are caused by similar mechanisms. Stability is determined by analyzing the patterns of injured structures.

To understand the biomechanical stability of fractures, the spinal column can be divided into three columns (Fig 1). The anterior column contains the anterior vertebral body, the anterior longitudinal ligament, and the anterior portion of the anulus fibrosus. The middle column contains the posterior half of the vertebral body, the posterior longitudinal ligament, and the posterior aspect of the anulus fibrosus. The posterior column consists of the posterior elements of the spine, the facet capsules, and the interspinous ligaments (15,16). As a general rule, two of these columns or restraint systems must be intact for the spine to be intrinsically stable. If two contiguous columns or the middle column is disrupted by trauma, congenital disease, or surgery, the spine is considered unstable. Internal fixation and fusion allow rapid correction of the instability.

By using this three-column concept of the spine, Denis (16) described four patterns of injury to the spine. Compression fractures involve compression of the anterior column. Burst fractures result from compression of the anterior and middle columns. Chance fractures (seat belt injuries) result from distraction of the middle and posterior columns, and fracture dislocations result from anterior compression and distraction of the middle and posterior columns with a rotational shear (17).

The goal of fracture treatment is anatomic reduction and stabilization, with restoration of normal anatomy and function, allowing early mobilization (18). Treatment of spinal trauma should decompress the spinal canal, prevent further mechanical damage to nerves or vessels, reduce the displacement, restore the mechanical integrity of the spine, and prevent later deformities (19). Nonsurgical treatment of fractures requires months of bed rest.

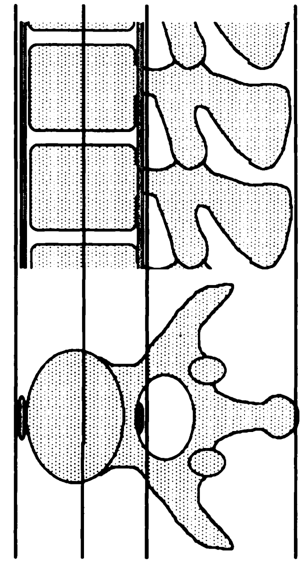


Figure 1. Drawing of the spine in sagittal and axial projections shows the three-column approach to understanding spine stability. (Drawing courtesy of Marj Heare, MD, Department of Radiology, North Colorado Medical Center, Greeley, Colo.)

Surgical correction and internal fixation restore alignment, decrease recovery time, and sometimes improve neurologic function (20).

■ FRACTURE HEALING

Fracture healing requires apposition of the fracture surfaces and some degree of stability, which, in the spine, often necessitates placement of internal fixation devices. Traction and halo devices are usually limited to unstable fractures of the cervical spine, which require distraction to maintain alignment. Current techniques are designed to reduce and stabilize the fracture with minimal additional bone or soft-tissue injury. Early movement and rehabilitation help prevent disuse osteopenia, stiffness, and loss of motion. Risks of internal fixation include malunion, nonunion, and infection but have been minimized with modern surgical techniques.

Many different techniques of reduction and fixation are used depending on the patient, type and location of the fracture, associated injuries, and experience of the surgeon. Spinal fixation is complex, and each case is unique. The ideal fixation is not always possible, and modification of techniques, implants, or both may be needed to accomplish the treatment goals.

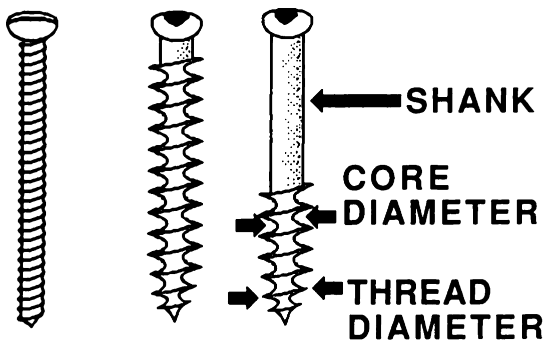


Figure 2. Drawing shows the difference between a cortical screw (left), a cancellous screw (center), and a partially threaded cancellous screw (right). (Reprinted, with permission, from reference 21.)

■ BASIC HARDWARE AND GRAFTS

Screws can be used as the primary means of repair or for the attachment of other fixation devices. A number of different screw types are used in the spine; they are available in various lengths, pitches, shank, and thread diameters.

Figure 2 (21) shows the difference between the two major screw types and defines some identifying characteristics. Cortical screws have closely spaced threads that are designed to gain maximum purchase in cortical bone. They are used primarily to attach plates. Before these screws are placed, the bone must be drilled and tapped (prethreading of the bone with a special cutting device). Cancellous screws have deep threads that are widely spaced and are designed to obtain optimal purchase in cancellous bone. Cannulated screws are hollow and are available in either a cortical or cancellous thread pattern. They can be placed over a guide wire or pin for more accurate placement.

Lag screw refers to the way a screw is used rather than to a particular type of screw. Lag screws are used as a primary means of repair and function by pulling two fragments together. A screw functions as a lag screw when the threads gain purchase only in the far fragment. When the screw is tightened, the head of the screw in the proximal fragment and the threads in the distal fragment are brought together. Usually partially threaded cancellous screws are used as lag screws, although cortical screws can be used if the proximal fragment is overdrilled.

Plates can be attached with screws to the anterior portion of the vertebral body or the posterior elements of the spine. There are a great number of specialized plates used exclusively in the spine, and these are discussed in separate sections by location.

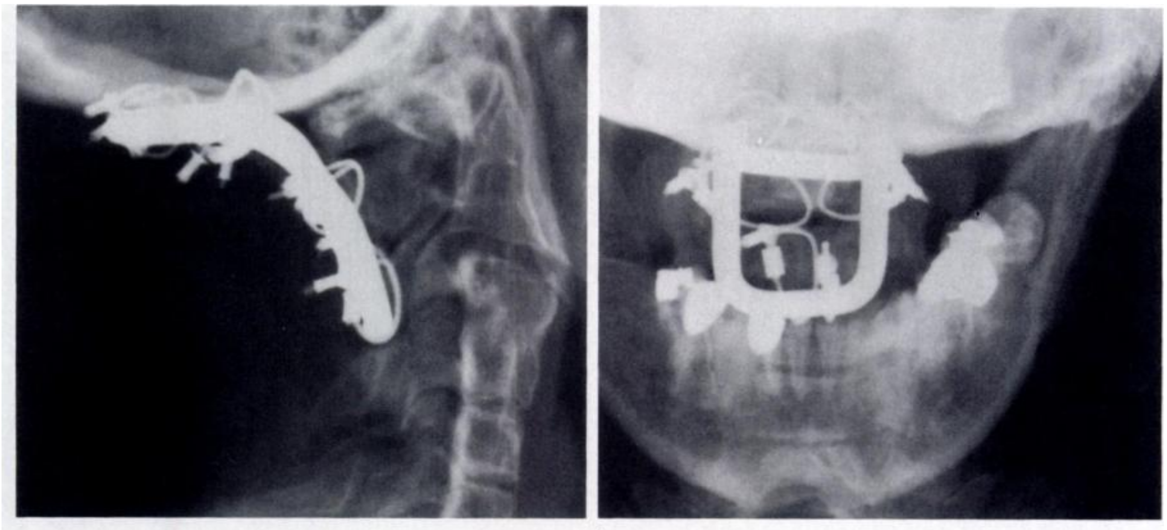
Stainless steel wire can be used as a primary or supplementary method of fixation, such as attaching corrective rods. Wire is available in variable diameters and can be used singly or in pairs. Songer cables are made of braided titanium or stainless steel wire and are more pliable than wire. The ends are held in place by a crimped metal collar.

Rods are used primarily in the thoracic and lumbar spine to provide stability over a long segment. They include the Luque system, which is attached to the lamina and spinous processes with wire; Harrington rods, which are attached with hooks; and the Cotrel-Dubousset, Texas Scottish Rite Hospital, and Isola systems, which can be attached with hooks or transpedicle screws.

Methylmethacrylate was introduced in the early 1960s and can be used as a primary fixation to fill bone defects, strengthen screw sites, or augment other spinal fixation (22). Methylmethacrylate is not a glue, but a cement, and forms a mechanical interlock with bone.

Bone graft is commonly used to promote fusion and increase the size of the fusion mass. Autograft refers to bone harvested from the individual receiving the graft. Allograft or homograft refers to bone from a donor, usually a cadaver. A posterior fusion includes bone graft material placed along the facets and lamina, which may extend up to and include the spinous processes. An intertransverse fusion includes bone graft between the transverse processes. An anterior fusion involves fusion of the vertebral bodies.

Vertebral bodies that are infected, crushed, or involved with tumor must often be removed. This leaves a large defect and an unstable spine. Replacement of the vertebral body to maintain height and fusion to maintain stability are necessary. Methylmethacrylate can be used to achieve both. Structural graft or strut grafts are also commonly used to regain vertebral body height after resection or to treat compression fractures. Autologous or homologous sections of rib, fibula, or tibia are most often used as structural allografts. Often pins (Steinman pins) or wire mesh are used to prevent the methylmethacrylate from migrating. Metallic devices, around which graft material is placed, or titanium cages packed with bone graft can be used. The following is a review of specific fixation techniques used in the cervical spine.



a. b.

Figure 3. **(a)** Lateral radiograph shows a Luque rectangle that has been prebent to accommodate the occipitocervical junction in a patient with Klippel-Feil syndrome. **(b)** Anteroposterior (AP) radiograph shows the closed loop of stainless steel, attached with wire cables (Songer cables) that pass through holes in the skull. The ends of the cable are held in place by a crimped metal collar. Metal plates called occipitocervical plates can also be used in this location.

■ CERVICAL SPINE

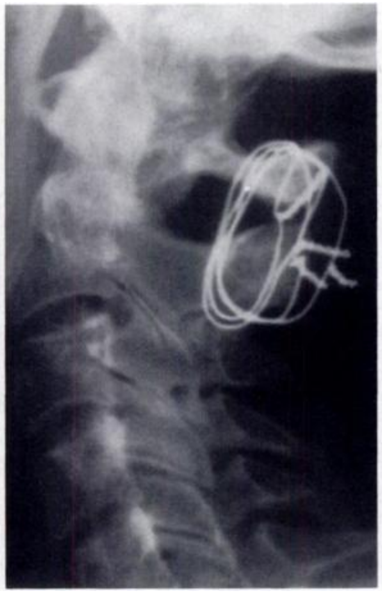
Because of the unique biomechanics of the occipitocervical and atlantoaxial articulations, there are differences between the techniques of fixation and fusion employed in the upper and lower cervical spine. The techniques used for fixation in the cervical spine include anterior and posterior approaches with use of screws, plates, wires, cables, bone graft, and methylmethacrylate.

• Upper Cervical Spine

Occipitocervical plates are special plates that are prebent to accommodate the base of the skull. Luque rectangles are smooth, round rods that are prebent into a square or shaped as needed to accommodate the occipitocervical junction. They are attached to the skull with wire or cable (Fig 3).

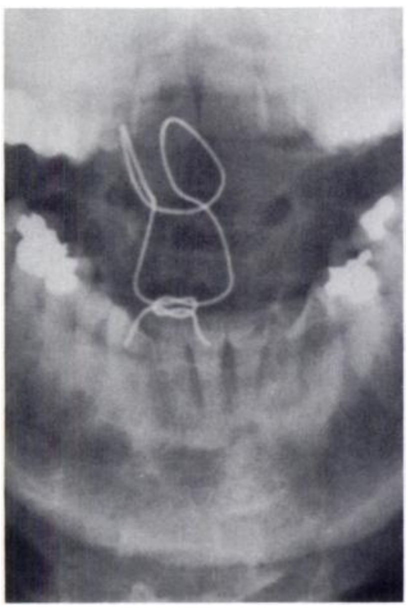
Several wiring techniques are used posteriorly in the upper spine for cervical instability. The Gallie technique used for C-1 to C-2 fusions is accomplished by passing stainless steel wire around the posterior arch of C-1 and under or through the spinous process of C-2 and is referred to as a McLauren fusion (Fig 4). Usually, the ends of the wire are twisted together rather than tied to allow the tension to be adjusted during the procedure. A Brooks fusion uses paired wires or Songer cables, which pass under the arch of C-1 and around the lamina of C-2 (Figs 5, 6). Both of these techniques prevent flexion and, to some degree, subluxation at this level. Bone graft material is usually placed between the spinous processes to facilitate fusion.

4a.

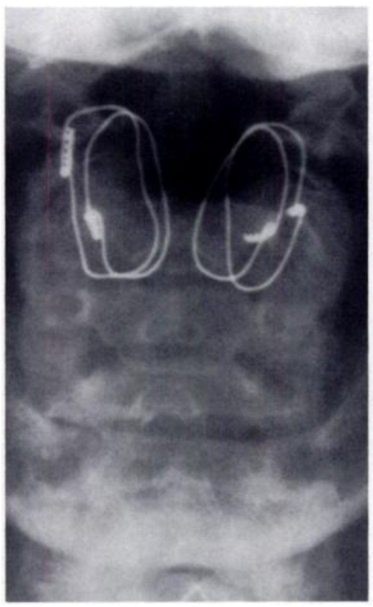


5a.

6a.



4b.



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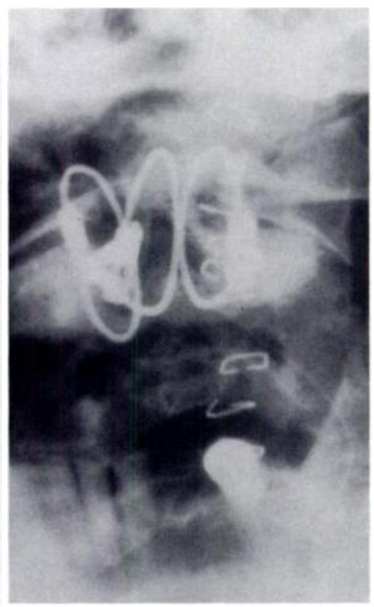
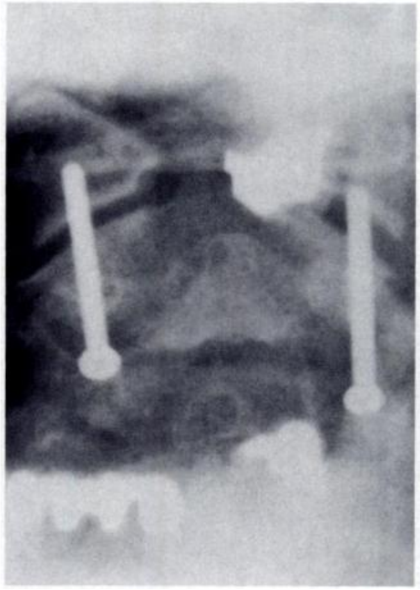


6b.

Figures 4–6. **(4a)** Lateral radiograph shows a McLauren fusion of C-1 to C-2 with the use of stainless steel wire and the Gallie technique in a patient with severe rheumatoid arthritis and cervical instability. The wire passes around the posterior arch of C-1 and the spinous process of C-2. Remnants of bone graft material can be seen posterior to the wire. **(4b)** AP radiograph shows the ends of the wire tied together. This technique prevents flexion and, to some degree, subluxation at this level. **(5a)** Lateral radiograph of the cervical spine shows a posterior fusion of C-1 to C-2 with the Brooks technique, with two paired wires passing through the arch of C-1 and around the lamina of C-2. **(5b)** AP radiograph shows the two pairs of sublaminar wire. **(6a)** Lateral radiograph of the cervical spine shows a posterior fusion of C-1 to C-2 with the Brooks technique, with Songer cables passing through the arch of C-1 and around the lamina of C-2, surrounded by methylmethacrylate cement. **(6b)** AP radiograph shows the three cables used.



7a.

7b.

8.

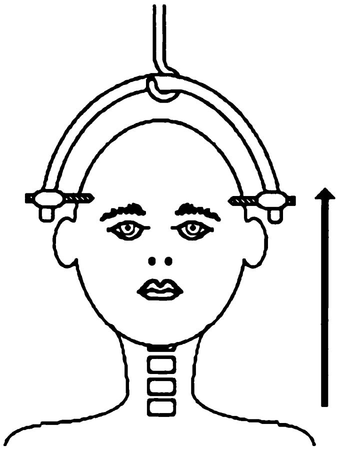
9.

Figures 7–9. AP (**7a**) and lateral (**7b**) radiographs of the upper cervical spine in a patient who has undergone a C-1 to C-2 fusion show cortical screws passing through the articular pillars of C-2 into the lateral masses of C-1. (**8**) Lateral radiograph shows two partially threaded cannulated screws that pass through the inferior cortex of C-2 and into the odontoid for fixation of a type II odontoid fracture. (**9**) Photograph shows two Knoringer screws designed for the repair of type II odontoid fractures.

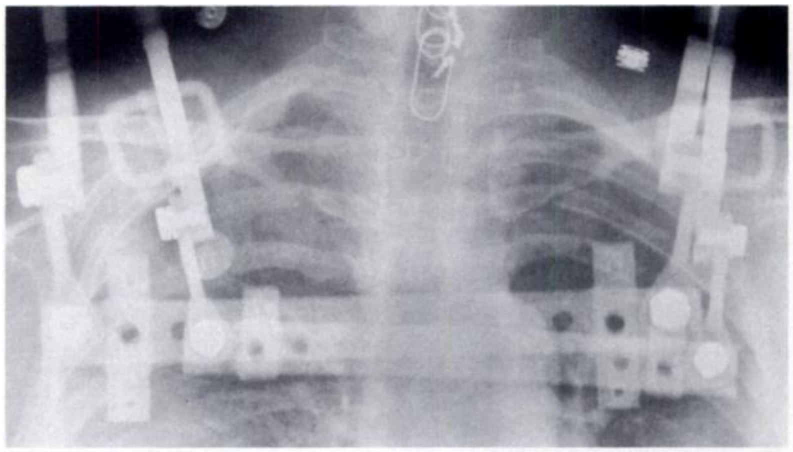
Transarticular screws pass through the facet joints and can be used for C-1 to C-2 fusions when placed through the articular pillars of C-2 and into the lateral masses of C-1 (Fig 7). Odontoid fractures can be stabilized by passing partially threaded cannulated screws through the inferior cortex of C-2 and into the odontoid (Fig 8); they function as lag screws. The hollow center of cannulated screws allows them to be accurately advanced over guide pins or wires. The Knoringer screw (Fig 9) is similar in design and function to the Herbert screw used in the hand and wrist. The Knoringer screw is designed for the repair of type II odontoid fractures. It is threaded at both ends with a smooth shaft in the middle, it has no screw head, and the threads at the two ends have a different pitch. When the shaft is placed across the fracture and the screw is tightened, compression is achieved because of the differential advancement rate of the two ends of the screw.

Gardner-Wells traction tongs (Figs 10, 11) attach to the temporal bone of the skull and can be used to immobilize the neck for treatment of dislocations or unstable fractures of the cervical spine. Usually, only the tong portion of the device is seen on lateral radiographs of the skull.

Halo devices consist of a partial or complete solid ring that is attached to the calvaria with set screws and supported by a rigid brace that encompasses the shoulders (Fig 12), chest, or pelvis. They are used to provide distraction in the treatment of cervical fractures. The connecting rods are adjustable, allowing three-dimensional control of the skull-shoulder relationship.



10.



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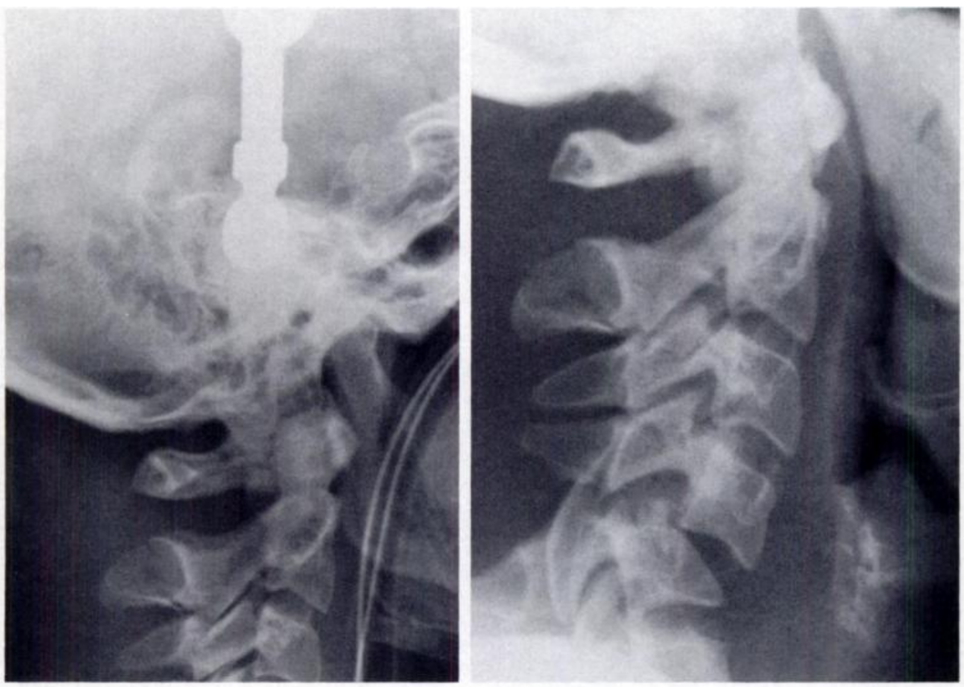
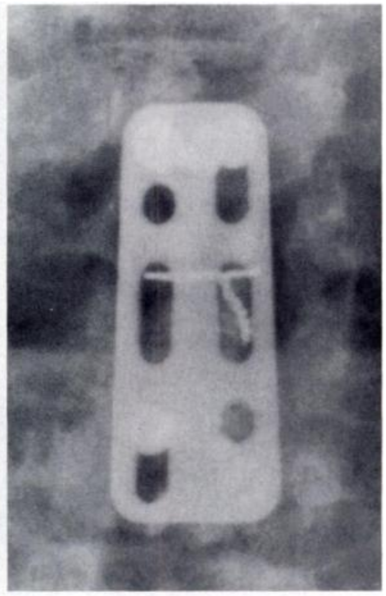


11a. **11b.**

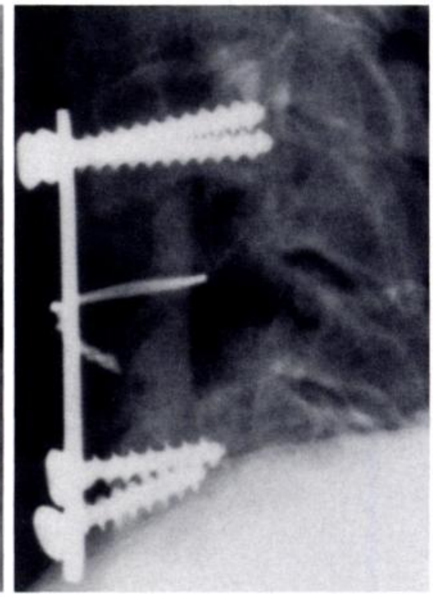
Figures 10–12. **(10)** Drawing shows Gardner-Wells traction tongs attached to the skull and used to immobilize the cervical spine by providing traction for the treatment of dislocations and unstable fractures. (Drawing courtesy of Marj Heare, MD, Department of Radiology, North Colorado Medical Center, Greeley, Colo.) **(11)** Lateral radiographs show the lower portion of Gardner-Wells traction tongs attached to the skull in a patient with a fracture dislocation at C-5 to C-6 **(a)** and the fracture dislocation before treatment **(b)**. **(12)** Upper portion of an AP chest radiograph shows the shoulder support for a halo collar. Note the interspinous wiring in the lower cervical spine.

Figures 13–15. **(13)** Lateral radiograph shows segments of fibula used as structural allografts for an anterior cervical fusion in a patient who underwent diskectomy of C-3 to C-6. **(14a)** AP radiograph shows a Caspar plate placed for an anterior cervical fusion. The plate has two rows of oval holes through which cancellous screws have been placed into the vertebral bodies. **(14b)** Lateral radiograph shows a section of fibula placed as a structural allograft in the vertebral body removal site and held with a single circlage wire against the plate. **(15a)** AP radiograph shows an anterior cervical fusion of C-5 to C-7 with an H-shaped plate and six transcortical screws. **(15b)** Lateral radiograph shows the ideal position of the transcortical screws.

13.

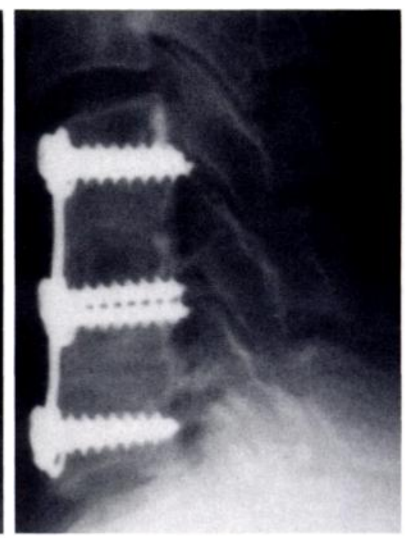


14a.



14b.

15a.



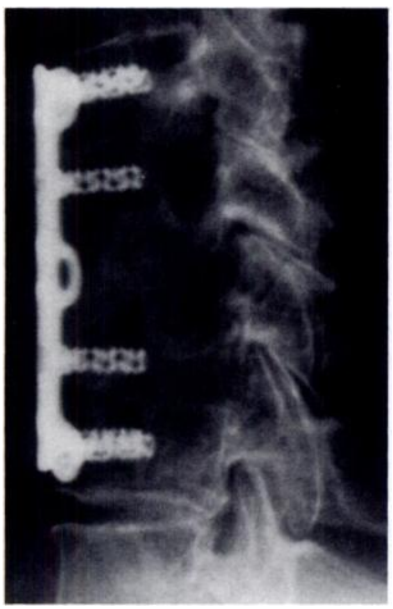
15b.

Figures 16, 17. **(16a)** AP radiograph of a cervical spine shows a Morscher cervical spine locking plate used for an anterior fusion from C-3 to C-6. **(16b)** Lateral radiograph shows the low profile of the Morscher plate and the characteristic fenestrated screws. AP **(17a)** and lateral **(17b)** radiographs of a cervical spine show a Morscher cervical spine locking plate used for an anterior fusion from C-4 to C-5. The structural allograft is shown in **b.**

16a.

17a.

17b.



16b.

• Anterior Approach to the Lower Cervical Spine

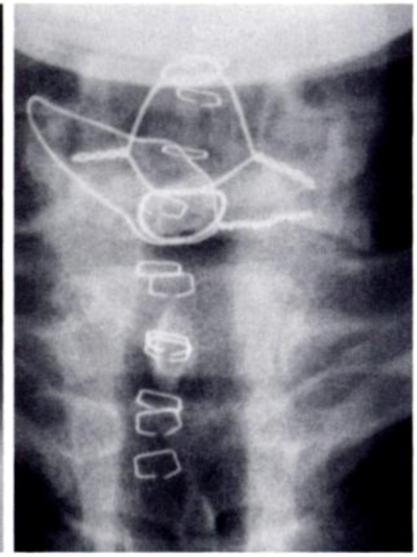
Anterior cervical fusions involve fusion of the vertebral bodies and commonly include the use of plates and structural allografts. Small plates are used to minimize impingement on the prevertebral and parapharyngeal soft tissues. A Smith-Robinson fusion involves removal of the disk and placement of bone graft. Hardware is not always necessary for one-level fusions (Fig 13). A Cloward fusion includes removal of a portion of the vertebra (23).

Several different conventional stainless steel plates are used in the cervical spine, including Caspar plates, which are wider at one end and shaped like a trapezoid (Fig 14). They are slightly concave in cross section to accommodate the curve of the anterior vertebral body. The Caspar plate has two rows of oval holes through which screws are placed. H-shaped plates are thin stainless steel plates with a slight concavity to accommodate the shape of the anterior vertebral body (Fig 15). The edges of the plate flare out at the screw sites. Cortical screws, which pass through both the anterior and posterior cortex of the vertebral body, are referred to as bicortical screws and have greater holding power than screws anchored only into cancellous bone.

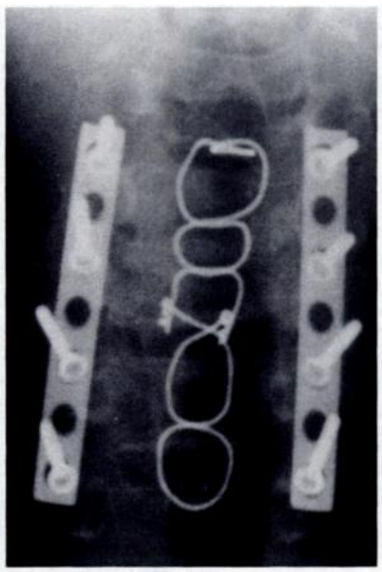
The Morscher cervical spine locking plate (Figs 16, 17) is also H shaped but has special cannulated screws and screw caps that lock the plate and screws together, preventing the screws from backing out. The screws have characteristic fenestrations that allow bone ingrowth, and, because they are locked to the plate, do not require transcortical purchase.

Figures 18–20. **(18)** AP view of a patient with an anterior column fracture and posterior ligamentous failure shows interspinous wiring and laterally placed plates. **(19a)** Lateral view shows a C-6 to C-7 facet fusion performed with wire. **(19b)** AP view of a patient with a fracture dislocation shows a second wire used to connect the spinous processes of these two vertebrae. **(20a)** AP view of a cervical spine shows sublaminar wiring on the right, with the lower wire wrapped around the spinous process for a posterior fusion of C-5 to C-7. **(20b)** Lateral view obtained in the swimmers position shows the sublaminar location of the wire.

19a.

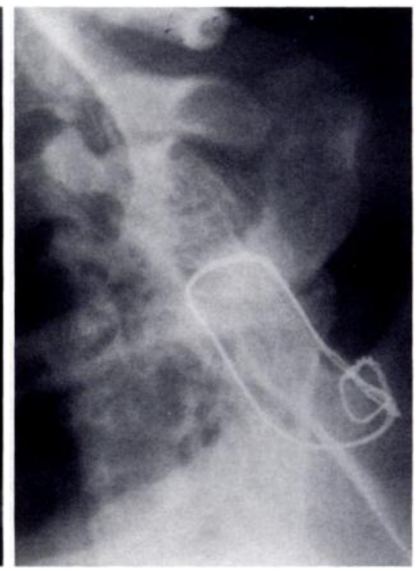


19b.



18.

20a.

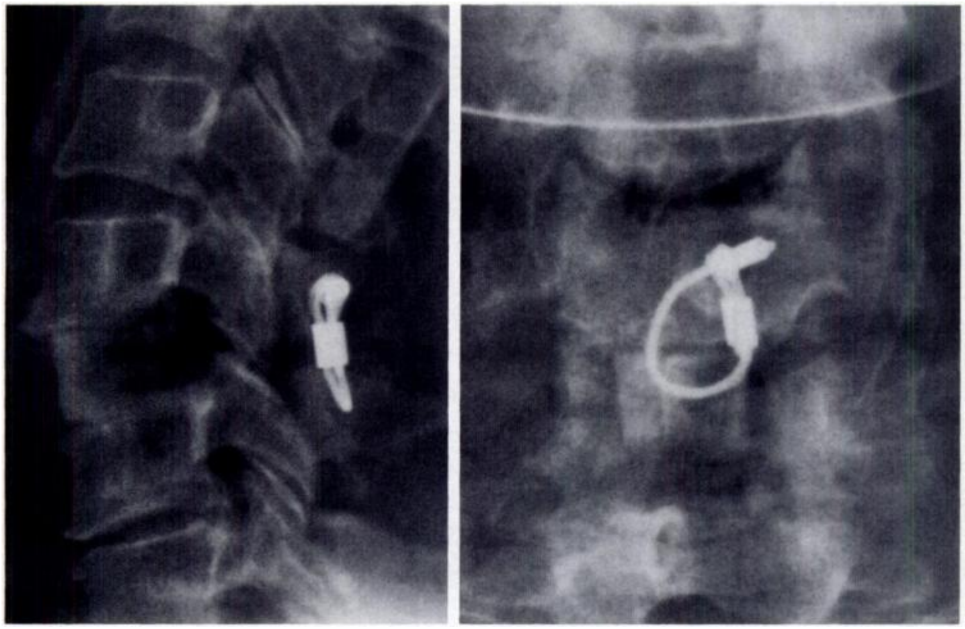


20b.

• Posterior Approach to the Lower Cervical Spine

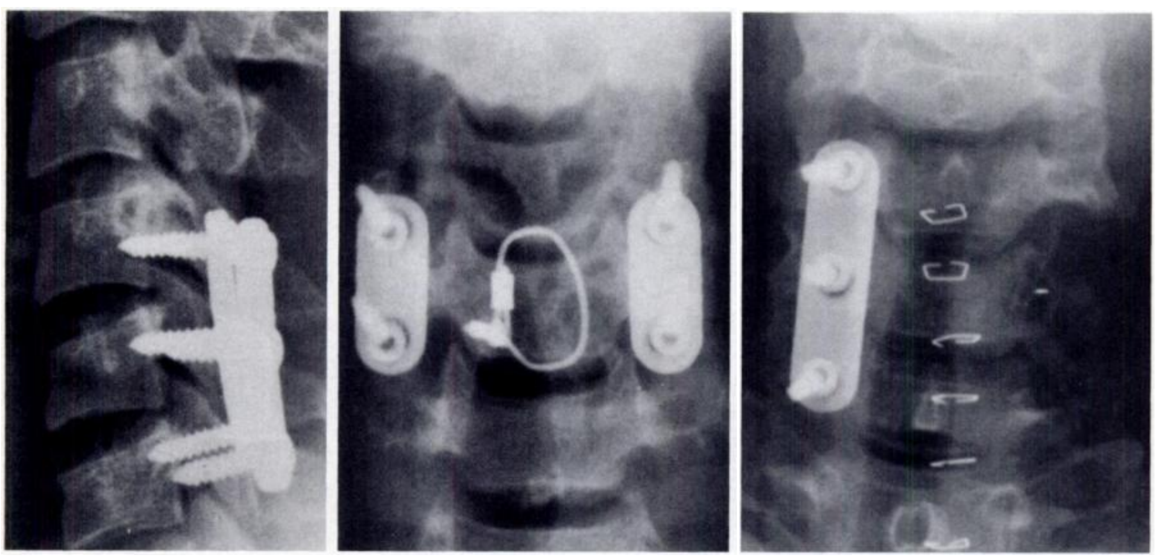
Interspinous wiring with the tension band principle technique can be employed in the lower cervical spine (Fig 18). A Rogers fusion involves wiring several spinous processes together, usually with bone graft. Wire is also used to hold cortical bone grafts in position. A Yale fusion involves fusion of facets with wire (Fig 19) (22). Single or paired wires can also be passed around the lamina for sublaminar fusions (Fig 20). Songer cable can also be used in the lower cercical spine, most commonly for interspinous fusion (Fig 21).

Haid plates (Figs 22–24) are specially designed for use in the cervical spine. They are made of titanium and are slightly concave in



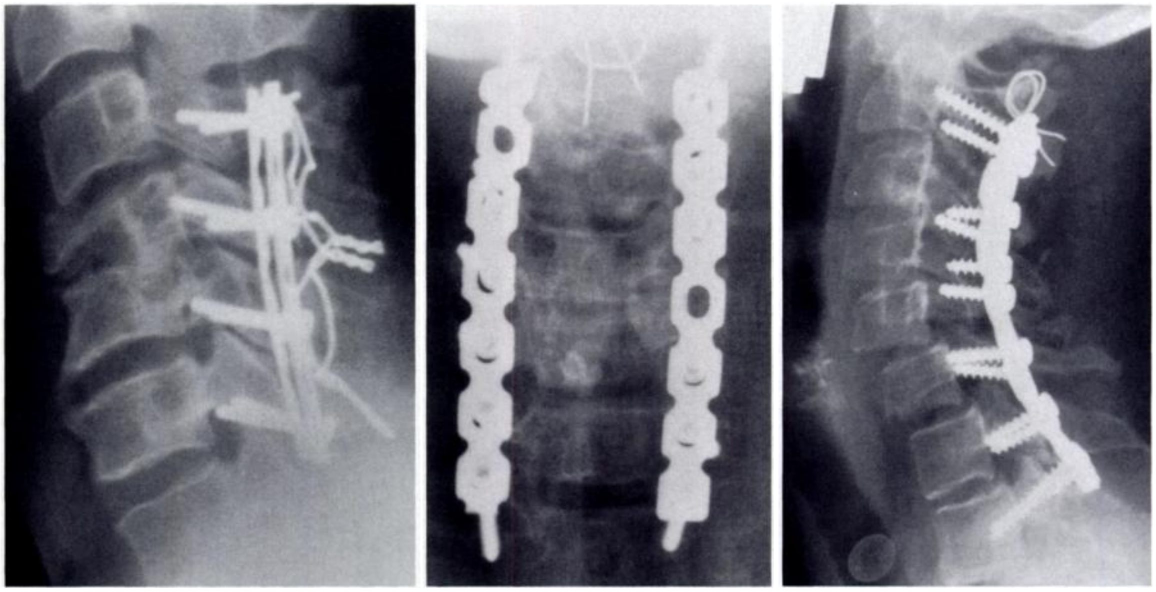
a. b.

Figure 21. **(a)** Lateral radiograph of the cervical spine in a patient who underwent a combined anterior and posterior cervical fusion of C-5 to C-6 shows a fibular strut graft interposed between the vertebral bodies and a Songer cable through the spinous processes. Additional graft material is seen between the spinous processes above. **(b)** AP radiograph shows the cable loop and crimped end holding the Songer cable.



22. 23. 24.

Figures 22–24. **(22)** Lateral radiograph shows two Haid plates attached to the lateral masses at the C-4, C-5, and C-6 levels with cortical screws in a patient with a hyperflexion injury. **(23)** AP radiograph shows two Haid plates and a single Songer cable attaching two spinous processes. **(24)** AP radiograph shows a Haid plate attached to the right lateral masses of C-5, C-6, and C-7 for stabilization after the resection of an osteoblastoma that involved the left lateral mass of C-6.



25. **26a.** **26b.**

Figures 25, 26. **(25)** Lateral radiograph of the patient in Figure 18 shows tubular plates attached to the articular pillars with cortical screws and interspinous wiring from C-3 to C-6. Note the bone graft material placed posteriorly. **(26a)** AP radiograph of a patient with a broken wire from a previous C-1 to C-2 fusion shows two malleable reconstruction plates attached to the articular pillars of C-2 through T-1. **(26b)** Lateral radiograph shows how the plates have been contoured for a complete cervical fusion in a patient with severe rheumatoid arthritis and multiple-level instability.

cross section to accommodate the shape of the posterior cervical spine. Screws placed through holes in the plate should enter the articular pillars. Tubular plates are thin plates with oval holes that have a semicircular profile (Figs 18, 25). They are used primarily in the extremities but can be used for long-segment posterior cervical fusions. Malleable reconstruction plates are pliable and can be attached to the spine by screws placed into the articular pillars (Fig 26). They are used primarily in areas with unusual contours, such as the pelvis, but can be used on the spine.

Hook plates have a hook at one end that grips the lamina and a hole in the other end for attachment to the articular pillars with a

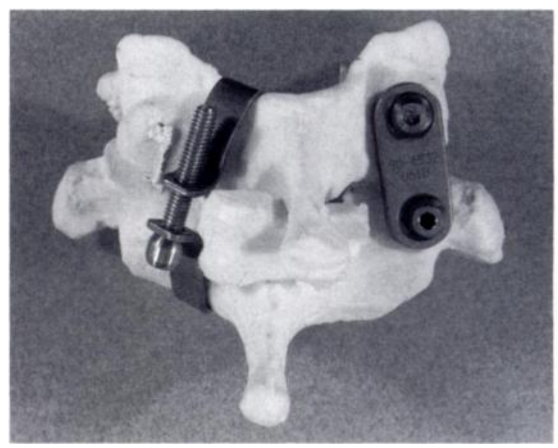
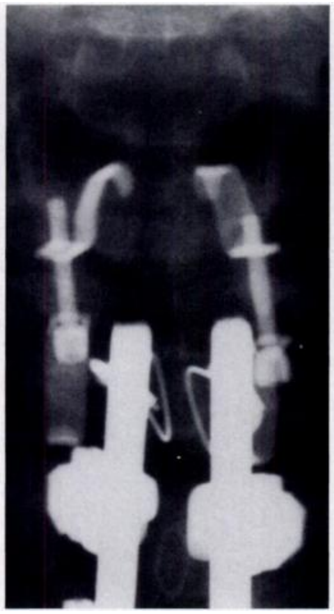


Figure 27. Model of the spine shows the posterior elements of two lower cervical vertebrae. Photograph shows a Halifax clamp (laminar clamp) with the two C-clamp ends gripping the lamina (left) and a titanium Haid plate with cortical screws entering the lateral masses (right). A small piece of bone (H-shaped graft) has been placed between the two spinous processes to facilitate bone union of the posterior elements.

28a.

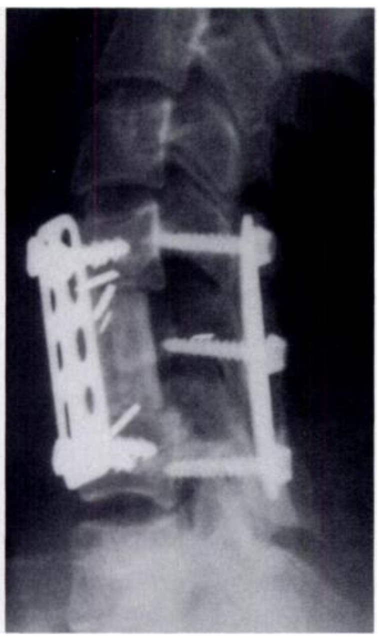


28b.

29.

Figures 28–30. **(28a)** Postoperative lateral radiograph of a patient with thoracic rods in place for a thoracic vertebral fracture shows two Halifax clamps (laminar clamps) spanning from C-5 to C-7 to stabilize a C6-7 subluxation injury. **(28b)** AP radiograph shows two Songer cables at the top of the rods. **(29)** Lateral radiograph shows a pair of Halifax clamps spanning the C-5 and C-6 lamina in a posterior fusion. **(30a)** AP radiograph of the patient in Figure 24 shows the addition of a Caspar plate anteriorly for a combined anterior and posterior cervical fusion. **(30b)** Lateral radiograph shows the Caspar plate anteriorly, with a structural allograft and a Haid plate posteriorly.

30a.



30b.

screw. Halifax clamps (laminar clamps) have two C-clamp ends that grip the lamina (Figs 27–29). The clamps consist of a screw that passes through two C-shaped hooks. When the screw is tightened, the two clamps are pulled closer together. Often, a small piece of bone (H-shaped graft) is placed posteriorly between the two spinous processes to facilitate bone union of the posterior elements.

Occasionally, anterior and posterior fixation techniques are used together. Sometimes they are placed simultaneously, and other times additional fixation is added because of failure, continued instability, or progression of disease (Fig 30).

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