Spinal Fixation

Part 2. Fixation Techniques and Hardware for the Thoracic and Lumbosacral Spine[1]

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Spinal fixation devices are used in the thoracic and lumbosacral spine to stabilize the spine, reduce deformities and fractures, and replace abnormal vertebrae. A bone fusion is usually attempted along with placement of the instrumentation because in most cases the hardware would eventually fail if it were used alone. The thoracolumbar spine is inherently unstable, and early operative intervention improves mobilization and rehabilitation. In some cases of lumbar spinal pain, surgical intervention is necessary for the treatment of conditions such as herniated disks, spondylolysis with spondylolisthesis, and degenerative disease with scoliosis. Surgical procedures consist of posterior (posterior elements) and anterior (vertebral body) fixation. Radiologists face continual changes in both surgical technique and instrumentation and should be knowledgeable about the devices available and the biomechanical principles that direct their use. They need to work with their surgical colleagues to become familiar with the techniques used at their institutions.

■ INTRODUCTION

Spinal fixation devices function to reduce deformities and fractures, stabilize the spine, and replace vertebrae because of disease or abnormality. Spinal fixation is used in the thoracic and lumbosacral spine to provide stability and restore anatomic alignment in the treatment of fractures, degenerative disease, and infection and tumors and to correct congenital deformities such as scoliosis. Internal fixation provides immediate stability, but the devices are of inadequate strength to withstand prolonged periods of stress and will eventually fail in most cases if bone fusion does not occur. Internal fixation is used to maintain position and alignment and to pre-

Abbreviation: AP = anteroposterior

Index terms: Spine, developmental defect, 30.14, 30.861 • Spine, diseases, 30.78 • Spine, fractures, 30.41 • Spine, infection, 30.20 • Spine, injuries, 30.42 • Spine, primary neoplasms, 30.30 • Spine, surgery, 30.45

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vent motion as the bone fuses. Fixation devices such as plates and rods are attached to the vertebral body or posterior elements by wire, screws, and hooks. Screws and wire can also be used as a primary means of fixation. The techniques can be divided into anterior and posterior approaches and by the method of attachment to the spine.

The history and basic principles of spinal surgery, including (*a*) reasons and techniques for fusion, (*b*) mechanisms of injury and fracture healing, (*c*) principles of stability, and (*d*) specific fixation devices used in the cervical spine, have been described previously (1). This article emphasizes the techniques and instrumentation used in the thoracic and lumbosacral spine (Table). Complications of spinal instrumentation will be addressed in a forthcoming article.

Devices and Techniques Used in the Thoracic and Lumbosacral Spine

- Screws
  - Pedicle
  - Cortical
  - Transcortical
  - Cancellous
  - Lag
  - Cannulated
  - Translaminar
- Wire
  - Sublaminar
  - Subpars
  - Interspinous
  - Songer cables
- Hooks
  - Laminar
  - Transverse process
  - Pedicle
- Posterior fixation
  - Luque rods
  - Harrington distraction rods
  - Harrington compression rods
  - Knodt rods
  - Cotrel-Dubousset (CD) rods
  - Texas Scottish Rite Hospital (TSRH) rods
  - Isola rods
  - Rogozinski system
  - O-ring fixators
  - Spinous process plates
  - Roy-Camille plates
  - Luque plates
  - Steffee plates
  - Dynamic compression plates
- Anterior fixation
  - Armstrong plate
  - Syracuse I plate
  - Dwyer device
  - Zielke device
  - Methylmethacrylate
  - Structural allografts
- External fixation
  - External spinal skeletal fixation
  - Orthosis and braces

■ REASONS FOR SURGERY

The most common reasons for spinal fixation in the thoracic and lumbosacral spine are fracture reduction, scoliosis correction, and stabilization in degenerative disease. Spinal trauma with associated fractures and instability is a common indication for spinal instrumentation. Over 160,000 Americans sustain vertebral column fractures each year (2), with most occurring in the thoracic and lumbar region (3). Because of the ribs, intercostal musculature, and angle of the facets, the thoracic spine is inherently stable, but the thoracolumbar spine is inherently unstable, and early operative intervention improves mobilization and rehabilitation (2).

Indications for surgical intervention include instability and compromise of the spinal canal. The most common causes of injuries to the thoracolumbar spine are motor vehicle accidents and falls. Fortunately, only a small percentage of these injuries result in neurologic deficits. The biomechanical principles involved in the late deformity of thoracolumbar fractures include axial compression and kyphotic angulation.

Scoliosis is a common indication for spinal instrumentation and fusion. Much of the spinal instrumentation used today was originally developed for the treatment of scoliosis. Indications for surgery include substantial angulation, pain, progression, pulmonary dysfunction, and neurologic compromise. Spinal fixation devices are used in the treatment of congenital, neuromuscular, degenerative, and idiopathic scoliosis. Congenital scoliosis generally results in short, sharply curved segments and is often treated at an earlier age than scoliosis from other causes. Surgical correction may require revision because of continued growth and deformity. The recognition of idiopathic scoliosis at a young age and the use of early treatment with a brace to prevent or slow the progression of the disease have decreased the need for surgery in the adolescent population.

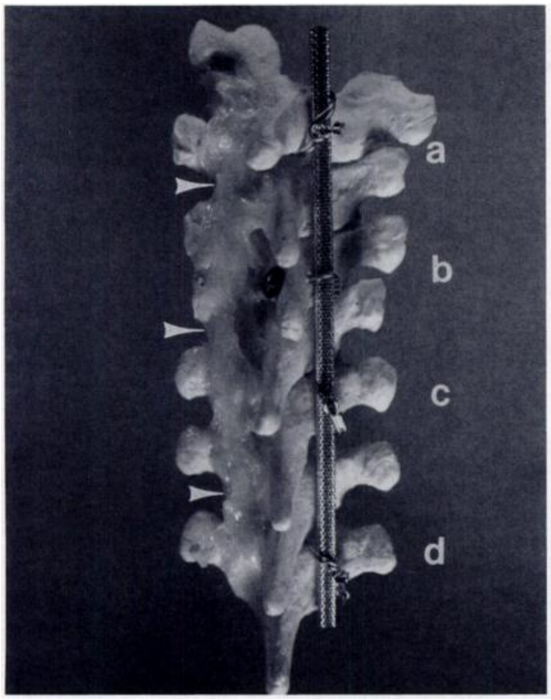


Figure 1. Photograph of the posterior spine shows four techniques used to attach rods. A Cotrel-Dubousset rod is used. The material on the left (arrowheads) represents bone graft placed for a posterior fusion. The four techniques are sublaminar wiring with a double strand of wire (*a*), interspinous wiring (*b*), a sublaminar Songer cable (*c*), and subpars wiring (*d*).

Instability as a result of surgery or degenerative disease, which is common in the lumbosacral spine, is another indication for fusion with instrumentation. Well-known conditions associated with lumbar instability include spondylolisthesis, degenerative spondylolisthesis, and rotoscoliosis. Controversy exists concerning the role of the lumbar disk as the "pain generator" and the need to use fusion in the presence of disk degeneration alone. A single recommendation for the surgical indications in patients with degenerative disk disease has not been determined. In patients undergoing laminectomy, the amount of deformity and extent of decompression helps determine the need for instrumentation and fusion. Certainly, if a level of the spine with preexisting scoliosis or spondylolisthesis is decompressed, fusion should strongly be considered.

Lumbar spinal pain is one of the most common medical problems among Americans. Exercise and conservative treatment provide relief in the majority of cases, but some patients require surgical intervention for the treatment of conditions such as herniated disks, spondylolysis with spondylolisthesis, and degenerative disease with scoliosis. Surgical procedures consist of posterior (posterior elements) and anterior (vertebral body) fixation.

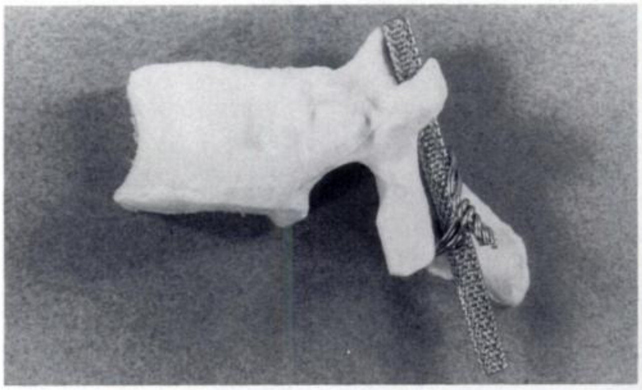
■ POSTERIOR FIXATION

A posterior midline incision is the most common approach for spinal surgery. It allows access to the posterior elements, spinal canal, and disk. A laminotomy involves removal of only the inferior margin of the lamina and is often performed to improve access for a microdiskectomy. A unilateral laminectomy refers to removal of the lamina on one side of the spine. A total or bilateral laminectomy involves removal of both the lamina and the spinous process. A laminotomy or laminectomy may be performed to provide access for diskectomy, decompression in trauma, or treatment of symptoms of lumbar stenosis. A laminectomy reduces spinal stability, and a multiple-level laminectomy with resultant instability is an indication for posterior fusion and fixation. These surgical defects in the posterior elements may be seen in isolation or in association with fixation devices.

The majority of fixation devices used in the thoracic and lumbosacral spine are placed posteriorly. The three primary techniques for attaching instrumentation to the posterior spine are (*a*) sublaminar and interspinous wires or cables, (*b*) laminar and pedicle hooks, and (*c*) pedicle screws. A fusion is usually attempted to provide long-term stability.

• Instrumentation Systems and Attachment Devices

There are several spinal fixation systems available that use paired or unpaired rods. Rods are commonly used for posterior fixation partly because of their ability to span a long segment. They are attached to the spine with wire, hooks, or screws, and sometimes several of these techniques are combined in the same patient. Wire and occasionally cable are used to attach rods directly to the posterior elements (Fig 1). Sublaminar wiring (Figs 1a, 2) is accomplished by passing a wire or pair of wires around the lamina and rod; the ends are usually twisted together. Generally, a smooth rod is used and is attached to the spine at every laminar level. Interspinous wiring (Fig 1b) involves passing a wire through a hole in the spinous process. A button (Drummond) pre-



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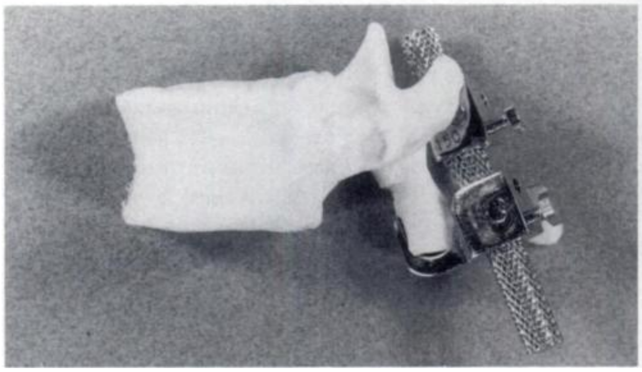

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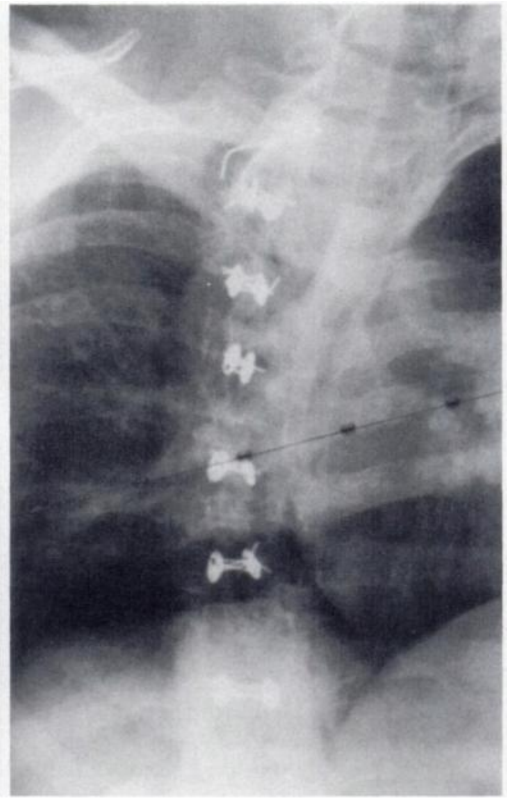

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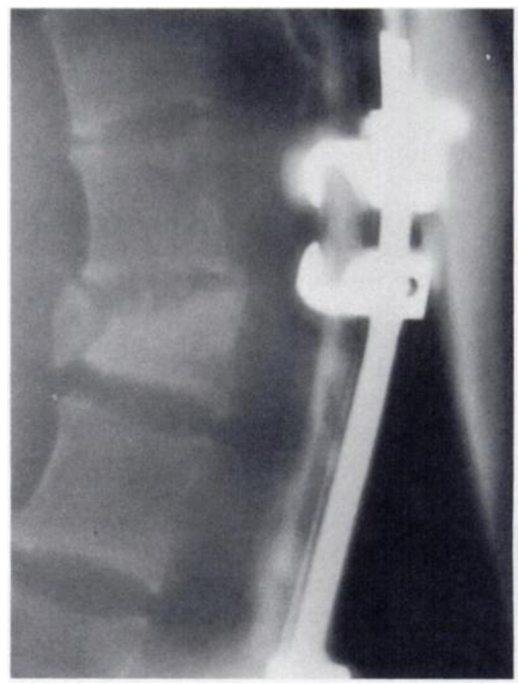
Figures 2–5. (2) Photograph of a spine sectioned in the sagittal plane shows the technique of sublaminar wiring as viewed from the side. A section of Cotrel-Dubousset rod has been attached to the posterior spine with a double loop of stainless steel wire that encircles the lamina. (3) Anteroposterior (AP) radiograph shows Drummond buttons and wires remaining in the spinous processes after removal of the rods, which had been attached with interspinous wires. (4) Photograph of a spine shows a pair of upgoing and downgoing laminar hooks used to attach Cotrel-Dubousset rods to the spine. (5) Lateral tomogram shows upgoing and downgoing hooks attached to a rod in the treatment of a compression burst fracture.



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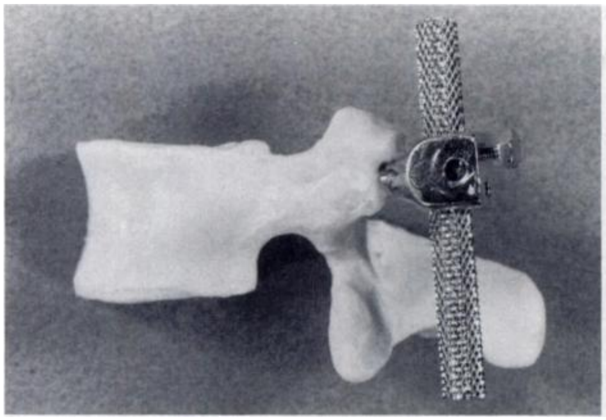

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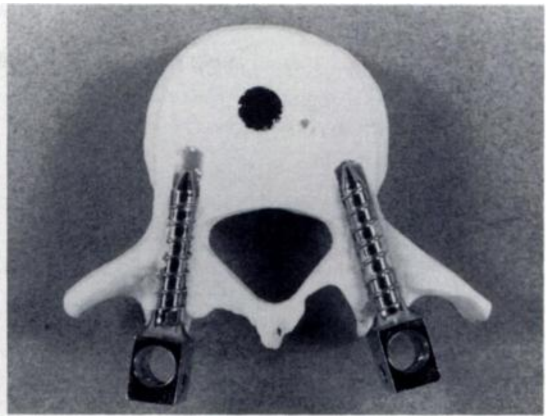

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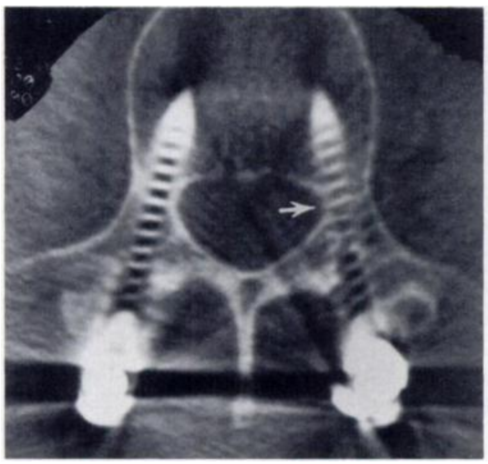


8.

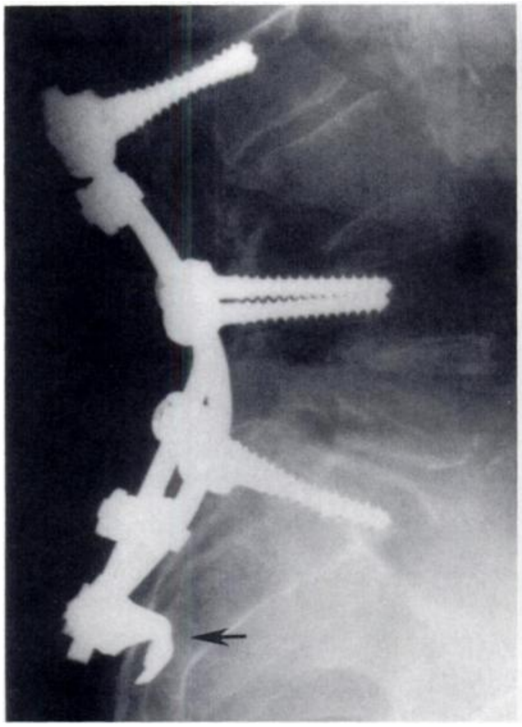
Figures 6–8. **(6)** Photograph of a spine viewed from the side shows the position of a pedicle screw attached to a short segment of a Cotrel-Dubousset rod. **(7)** Photograph of a spine sectioned in the axial plane shows the path of Cotrel-Dubousset–type pedicle screws as they pass through the pedicle and into the vertebral body. Ideally, the screws would be longer and pass further into the vertebral body. **(8)** Axial computed tomographic (CT) image shows optimal placement of the pedicle screw on the left. The screw on the right passes close to the medial cortex (arrow).

vents the wire from pulling through the bone (Fig 3). Plastic ties are occasionally used instead of wire. Sometimes a sublaminar cable or Songer cable is used in place of wire (Fig 1c). The cable is more pliable and less brittle than wire. One end of the cable is passed through a premade loop in the other end and is held in place by a metal crimp. Subpars wires are passed around the pars interarticularis instead of around the lamina, reducing the risk of cord damage (Fig 1d). When wires are placed at multiple levels, it is referred to as segmental wiring.

Laminar or sublaminar hooks, used as compression and distraction hooks, are available in a variety of sizes and shapes to accommodate the site of attachment (Fig 4). They are used on rods to allow the compression or distraction forces to be applied to the pedicles or laminae. They function as "hooks" as they engage the posterior elements by curving under (upgoing hooks) or over (downgoing hooks) the lamina. They are various sizes and are available to fit rods with threads, ratchets, and round or square ends. The hooks may be sharp or blunt, and some have ridges to help prevent slippage. The body of the hook fits over the rod and is held in place by lock washers, bolts, or set screws. Hooks were first used on threaded rods in 1964 by Knodt (4). Laminar hooks used in the thoracic spine are also called thoracic laminar hooks. Occasionally, transverse process hooks are used to provide a more lateral attachment site. Upgoing thoracic pedicle hooks have bifid tips designed to fit under the lamina and embrace the pedicle. Other specialized hooks include locking hooks with covers to prevent dislodgment and self-adjusting hooks for multiple-level placement in patients with scoliosis. An upgoing and a downgoing hook used together at the same level are referred to as a claw mechanism (Figs 4, 5) and greatly reduce the risk of dislodgment.

Pedicle screw fixation or transpedicle screws (Figs 6–10) are a more recently devised technique for attaching instrumentation and can be used with both plates and rod systems. Their use was first reported in 1969 by

Figures 9, 10. (9) Lateral radiograph shows Texas Scottish Rite Hospital hardware with pedicle screws in L-2, L-4, and the first sacral segment. A pair of sacral foraminal hooks are used in the lower sacrum (arrow) to obtain an additional level of stability. **(10)** Lateral radiograph shows Texas Scottish Rite Hospital hardware with pedicle screws in L-4 and S-1 and sacral foraminal cables used to attach the rods to the sacrum.



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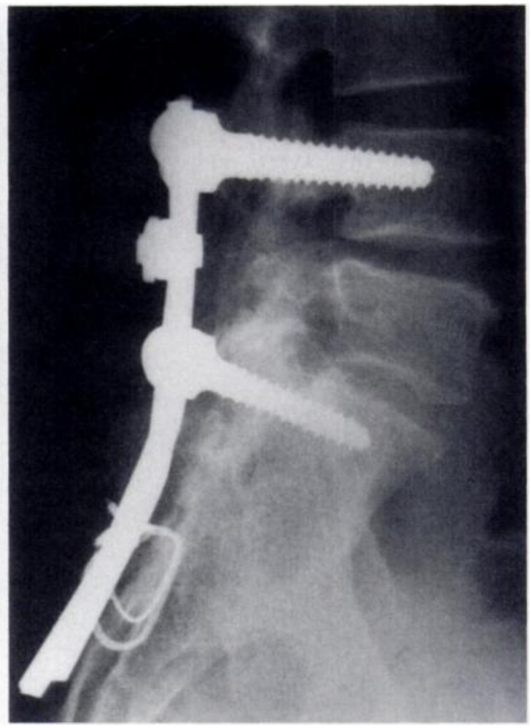
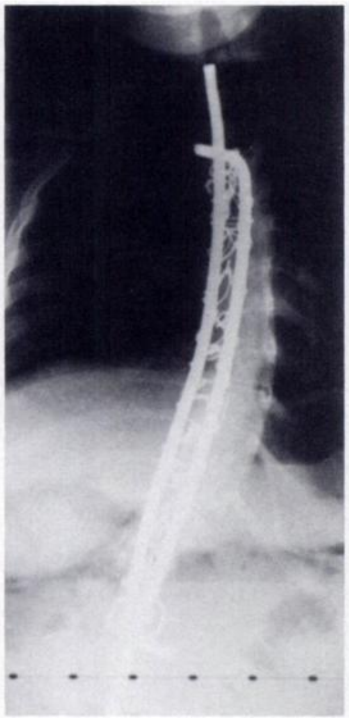


10.

Harrington and Tullos (5). There are several entry sites and orientation alternatives for pedicle screw placement. Generally, however, they are angled medially as they pass through the pedicle and into the vertebral body. They have a very shallow cancellous thread pattern to maximize the core diameter and therefore their strength. They are attached to rods or plates posteriorly with clamps, eyebolts, or set screws. When firmly anchored into intact bone, they resist loads in all directions. The three-dimensional rotational control makes them useful for correcting deformities (6). The screws need to be attached to only one vertebral body above and one below the site of injury, which reduces the number of levels involved in a construct and allows lordosis to be maintained. Pedicle screw strength is decreased when the screws are inserted too shallowly or when they are used in osteopenic bone.

Lumbosacral fusions necessitate attachment of the rods to the sacrum. This can be accomplished with pedicle screws, but their use is usually limited to S-1 and S-2. Sacral foraminal hooks (Fig 9) are specially designed laminar hooks that allow attachment of the lower end of the rods to the sacrum. They can be placed lower than pedicle screws and are often used along with screws to provide an additional level of stability. Sacral foraminal wires (Fig 10) can be used in place of hooks or screws to attach the lower portion of a rod system to the sacrum. The wires are more secure than the hooks, which can dislodge. The wires are also less bulky than the hooks and therefore are less likely to cause discomfort over the sacrum.

Figures 11, 12. **(11a)** Posteroanterior radiograph of a 19-year-old woman with scoliosis shows a pair of L-shaped Luque rods and segmental wiring. Luque rods can also be straight or bent. One disadvantage of Luque rods is the ability of the wires to slide freely on the smooth rod. **(11b)** Lateral radiograph shows a sublaminar path of the wires. **(12)** Drawing of the spine in the AP projection shows the corrective force applied to the spine with Luque rods and sublaminar wiring. As the arrows indicate, the force of lateral flexion is applied at each segmental level with the sublaminar wires.



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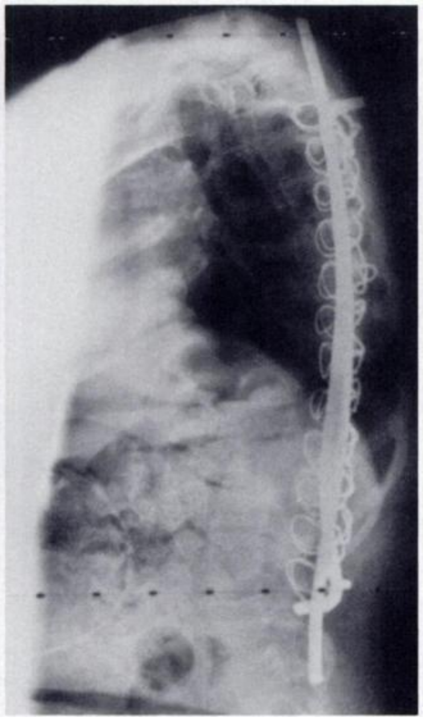

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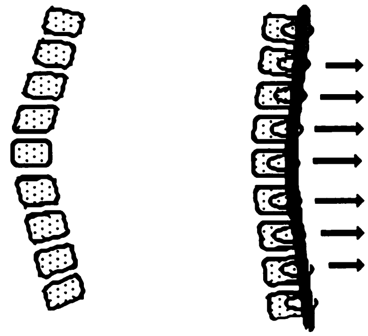
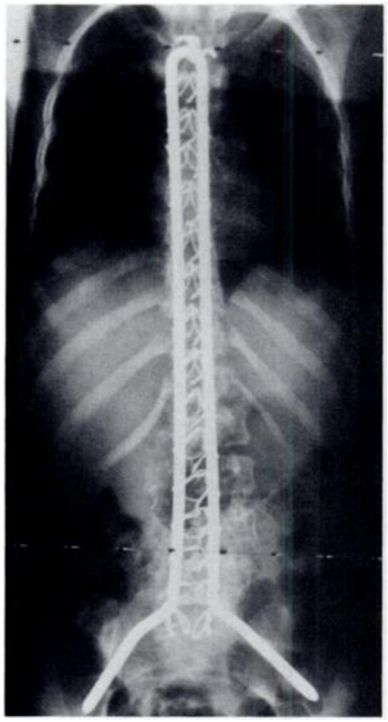


12.

• Rods

Luque rods (Figs 11, 12) are straight or L-shaped smooth rods (6 or 8 mm in diameter), designed and developed by Eduardo Luque, MD, in the 1970s for the correction of scoliosis (4,7,8). They are used most commonly to treat scoliosis but have also been used to treat trauma, tumor, degenerative spondylolisthesis, and disk disruption (6). The rods are attached to the lamina at every level with sublaminar wiring, which distributes the corrective force over multiple levels. To facilitate fusion, the facet joints are excised bilaterally. The flaval ligament is removed, and a wire is passed around each lamina. A 90° bend is placed at the end of the rod, and that segment is passed through a hole in the spinous process, preventing rotation and migration of the rod. The rods are prebent to the desired configuration before placement. This is approximately 10° less than the best measured correction during stretching or bending. Usually, no external support is necessary postoperatively. The primary principle applied in the correction of scoliosis is lateral flexion (Fig 12). The smooth Luque rod with segmental wires provides rotational and translational stability; resists flexion, extension, and lateral bending; but does not produce distraction or resist axial compression (2,6).

Figures 13–16. **(13a)** AP radiograph shows a Luque unit rod and segmental wiring with the Galveston technique. **(13b)** Lateral radiograph shows sublaminar wiring and an iliac extension inferiorly. **(14)** AP radiograph shows a Luque rectangle and sublaminar wiring used for the treatment of a thoracic spine fracture. **(15a)** AP radiograph shows the closed-loop design of a Luque rectangle used for a lumbosacral fusion. Note the bone graft material in the region of the transverse processes. **(15b)** Lateral radiograph shows interspinous wires with Drummond buttons used to attach the rectangle. **(16)** Lateral radiograph of the lumbosacral spine in a patient with a Luque rectangle that has been attached to the spinous processes of L-3, L-4, and L-5 with interspinous wires and Drummond buttons. This "floating ring" provided no substantial structural support and was replaced with a rod system. Note the L-4 pars defect.



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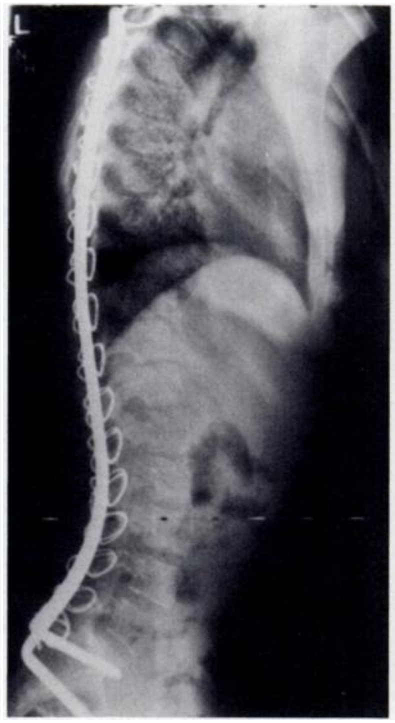

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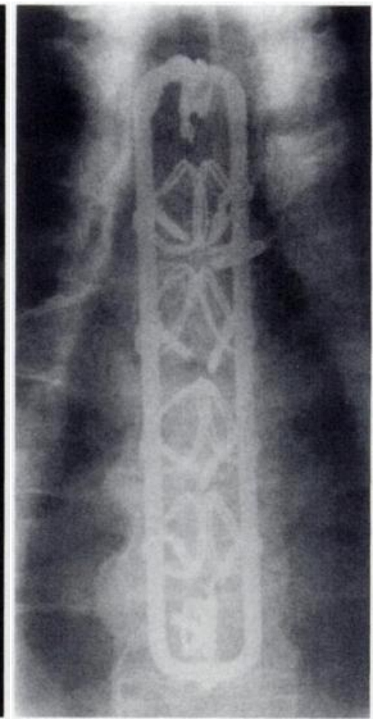

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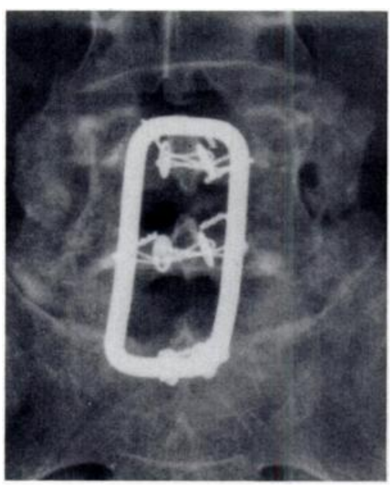

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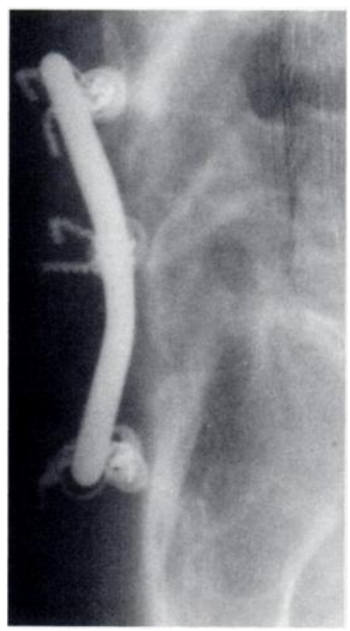
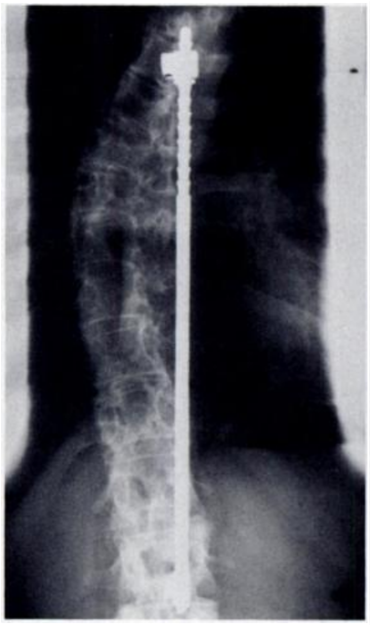


15b.

16.

Figures 17–20. **(17a)** AP radiograph shows a single Harrington distraction rod placed on the concave side for the treatment of scoliosis. **(17b)** Lateral radiograph shows the laminar distraction hooks at the ends. **(18)** AP radiograph shows interspinous wiring with a Harrington distraction rod (Wisconsin segmental wiring). **(19)** Oblique radiograph shows the lower end of a Harrington distraction rod with a hole, through which a wire can be threaded to provide increased stability and prevent rotation. **(20)** Drawing of a spine in the AP projection shows the forces applied to the spine with a Harrington distraction rod. The corrective force of distraction (arrows) is applied to the concave side at the ends where the hooks engage the spine.



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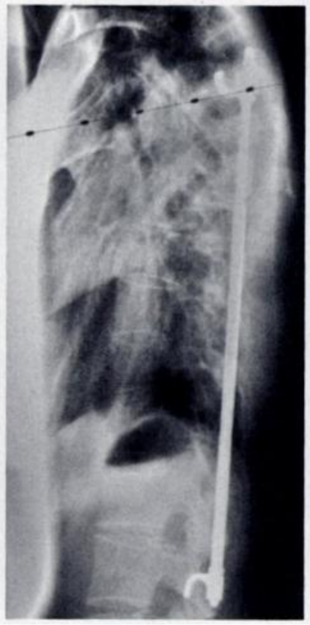

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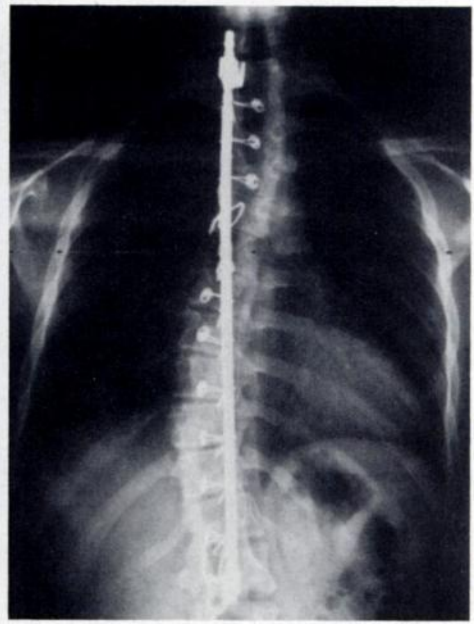

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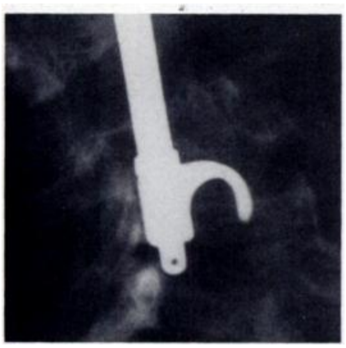

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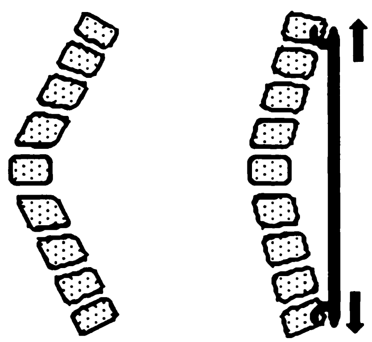

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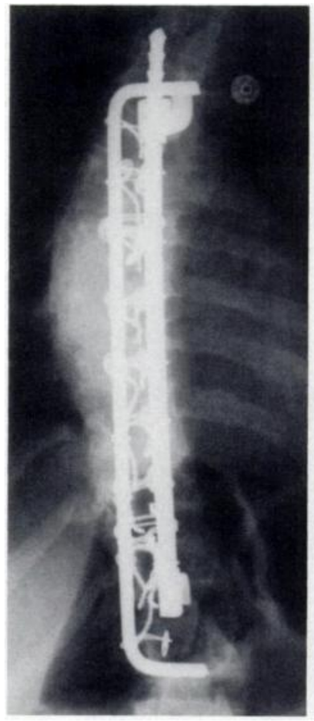
The Galveston technique (Fig 13) uses long Luque rods attached to the thoracic and lumbar spine with sublaminar wires. The rods continue down the spine and flare out laterally as they enter the iliac bones, providing a stable construct from the thorax to the pelvis. Usually, a single Luque rod curved back on itself to form two parallel rods, called a Luque unit rod, is used.

Two rods can be replaced with a flat rectangle or with one peaked at the midline (9,10). These are stiffer than two separate rods and provide more stability. These preshaped loops are known as O-ring fixators, rhomboid-shaped bars, Luque rectangles, or segmental spinal rectangles (Figs 14–16). A Hartshill rectangle has bends in the upper and lower ends to better accommodate the anatomy of the posterior spine. The rings are used for low back fusions and for the treatment of fractures and are attached to the spine with sublaminar wires or cables. Occasionally, interspinous wires are used, but this results in a much less stable construct. Their closed design prevents the wire from slipping off, as it might with short paired rods.

Harrington distraction rods (Figs 17–20) were originally designed for the treatment of scoliosis and have undergone only minor

Figures 21, 22. **(21)** AP radiograph shows a Luque rod with segmental wiring and a Harrington distraction rod with interspinous wiring used together in the treatment of scoliosis. **(22)** AP radiograph shows a Harrington distraction rod on a patient's left side and a compression rod that is threaded and has several nuts on the right side used in the treatment of scoliosis. The individual hooks and retaining nuts are clearly seen.



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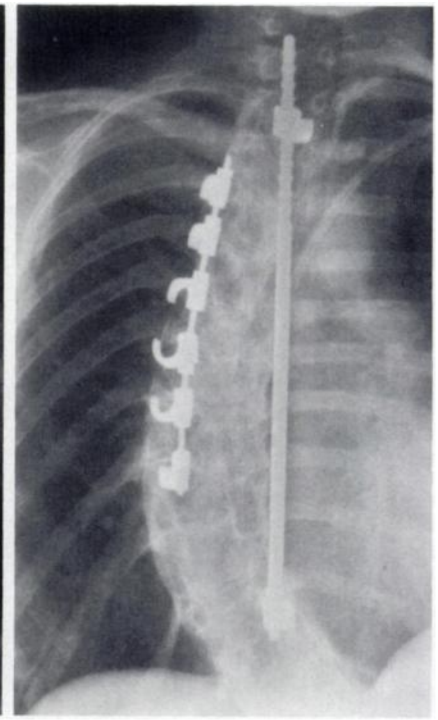

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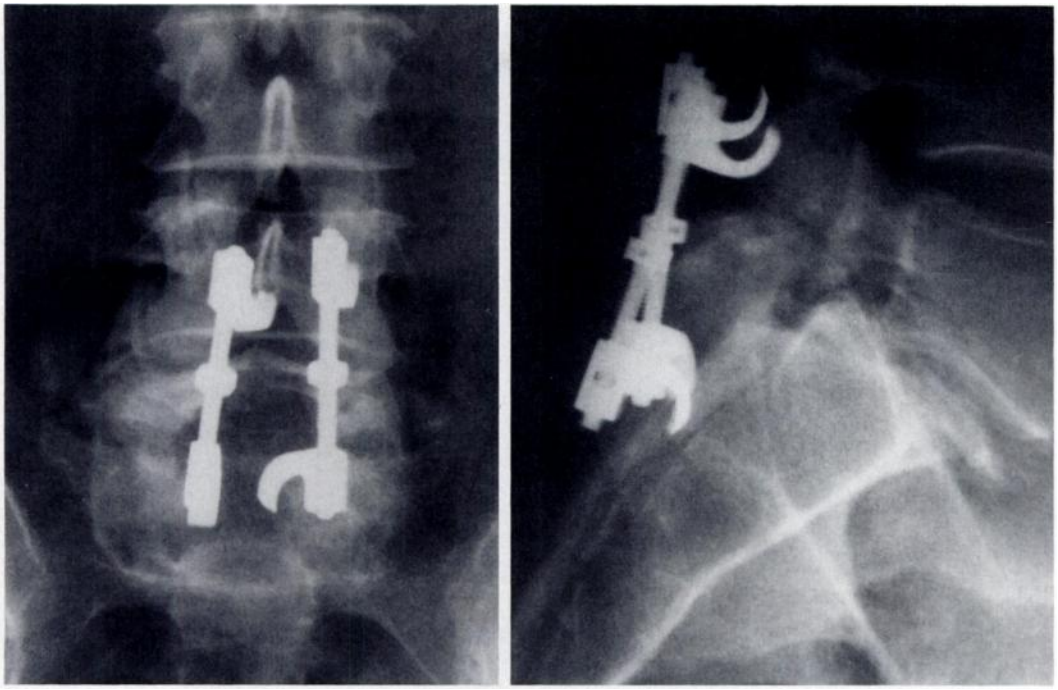
modifications since they were introduced in 1962 (11,12). Correction of scoliosis remains the major indication for their use, although they can be used in the treatment of other spinal deformities, trauma, and degenerative disease. The rods are smooth, with a collar at one end and ratchets at the other end. They usually span at least five vertebrae and transmit a distractive force to the spine at the ends where the laminar hooks are placed. The hook on the ratchet end is held in place with a special washer. Some rods have holes in the collar for wire sutures, which can be used to prevent rotation and migration (Fig 19). The technique involves rod placement across the deformity for stabilization, spinal fusion to maintain the correction, and immobilization to protect the correction until bone fusion occurs. The rods may be bent intraoperatively to accommodate thoracic kyphosis, lumbar lordosis, or an entire lateral correction that cannot be achieved. When used to treat fractures, the anterior longitudinal ligament must be intact, and two rods are used.

When used for scoliosis and fusion, the facet joints are excised and grafted. The distracted rod is placed in the cavity of the curve from the lowest to the highest vertebra to be fused. The upper hook is inserted into a thoracic facet joint rather than into the canal to minimize the risk of cord injury. Usually, the ratchet of the rod is placed cephalad, but rod direction can be reversed for high thoracic placement. The shaft should be appropriately sized so that only one or two ratchets extend below the upper hook. The excess rod is cut. An unbent rod is the most common cause of hook dislodgment. The corrective force of distraction is applied to the concave side only at the ends of the rod, where the hooks engage the spine. The primary principle of Harrington distraction rods for the correction of scoliosis is distraction with elongation (Fig



a. b.

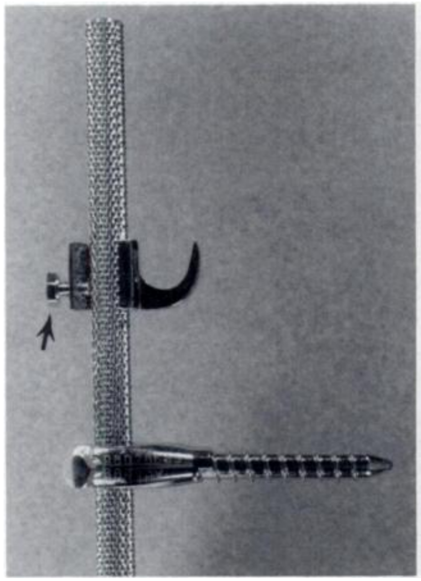
Figure 23. (a) AP radiograph shows Knodt rods used in the lumbosacral spine. (b) Lateral radiograph shows the laminar distraction hooks. Note the characteristic central turnbuckle.

20). The advantages of Harrington rods include availability, surgeon familiarity, and ease of insertion (2). Edwards sleeves can be placed over the rod to displace the central portion from the posterior elements, thus helping to maintain lordosis in the lumbar spine.

Occasionally, mixed systems are used, such as wiring with Harrington rods. Interspinous wiring with a Harrington distraction rod is referred to as Wisconsin segmental wiring (Fig 18). Sometimes a Luque rod with segmental wiring is also used on the convex side of the curve (Fig 21). This system combines the distractive forces of the Harrington rod with the lateral flexion forces of segmental wiring and is used in the treatment of scoliosis.

Harrington compression rods (Fig 22) are threaded rods of variable diameters (3 and 5 mm). They provide a compressive force when applied to the convex side of the spinal curve. The compressive force is applied to the spine with laminar hooks, which are held in place with threaded nuts. The lower hooks are placed under the lamina and the upper hooks above. The Harrington compression rods apply a force opposite that of distraction rods and are used primarily to correct spinal deformities (6). They are often used in conjunction with Harrington distraction rods in the treatment of scoliosis (Fig 22). The addition of a compression rod on the convex side of the curve provides additional correction, increases stabilization, and helps restore lordosis. Harrington instrumentation without fusion can be used in children but must be revised periodically (every 6–12 months) until the definitive fusion procedure is performed.

Knodt rods (Fig 23), introduced in the 1960s, are threaded distraction rods with a central fixed nut (turnbuckle) used in pairs in the lumbosacral spine. The two ends of the rod are threaded in opposite directions, and, when passed through threaded laminar hooks and turned, the opposing thread patterns result in a distractive force that moves the hooks away from each other.



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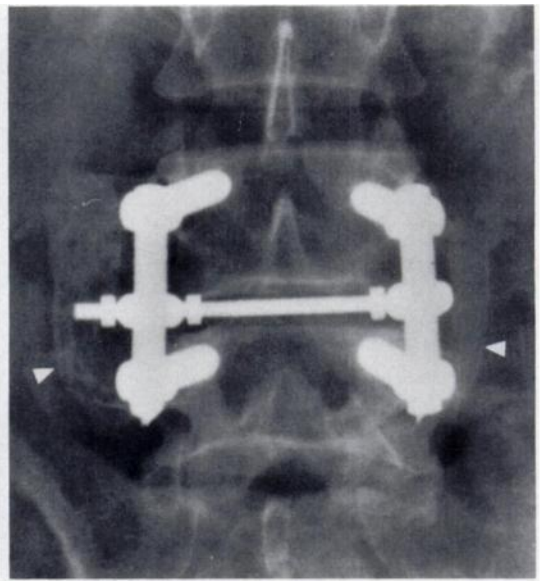

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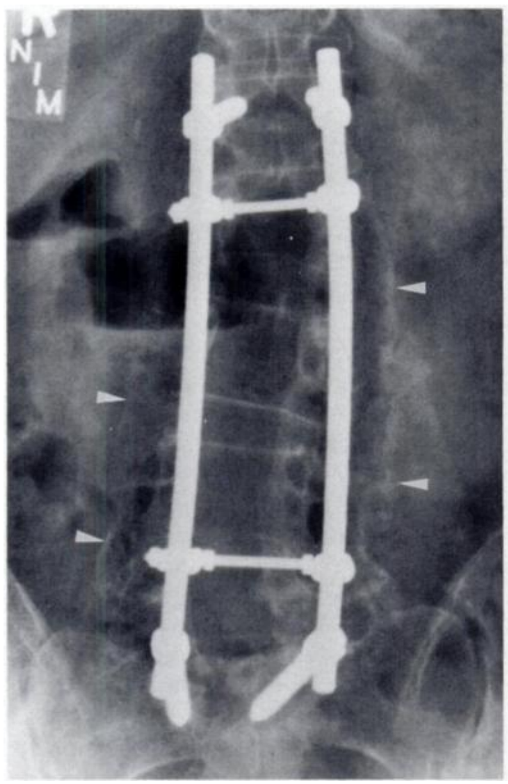

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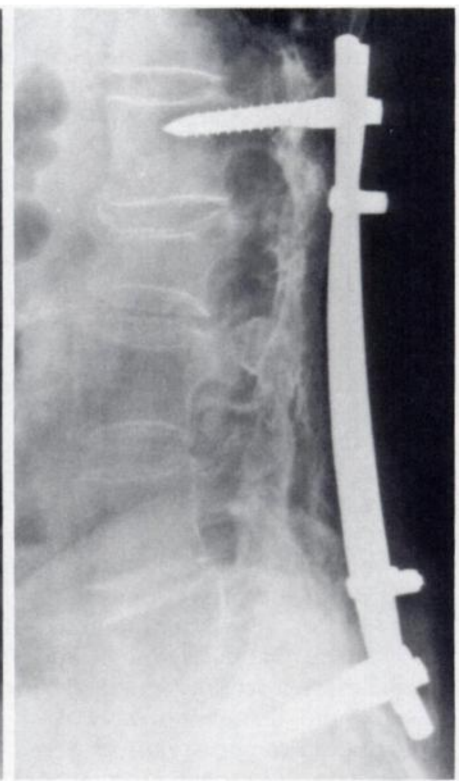
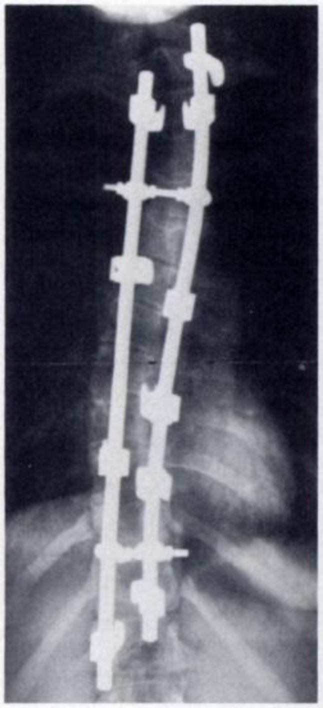


26b.

Figures 24–26. **(24)** Photograph shows a Cotrel-Dubousset rod with a laminar hook at the top and a pedicle screw lower down. Note the serrated surface of the rod and the small set screw (arrow) fixing the hardware to the rod. The serrated surface improves contact with the set screws and the hardware. **(25)** AP radiograph shows Cotrel-Dubousset rods and pedicle screws used in a single-level fusion after an L4-5 diskectomy. A lateral inter-transverse process fusion was performed, and bone graft can be seen spanning the transverse processes (arrowheads). This is an example of Cotrel-Dubousset rods used for posterior lumbar fusion stabilization rather than rotational correction of scoliosis. **(26a)** AP radiograph shows Cotrel-Dubousset rods and pedicle screws spanning L-1 to S-1, with a posterior fusion for a multiple-level laminectomy and an L-2 burst fracture. The fusion was extensive, spanning all of the laminectomy levels. Note the extensive bone fusion laterally (arrowheads). **(26b)** Lateral radiograph shows the L-2 burst fracture and posterior fusion.



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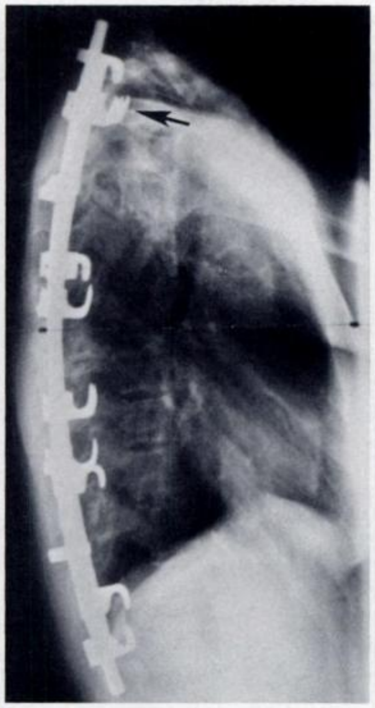

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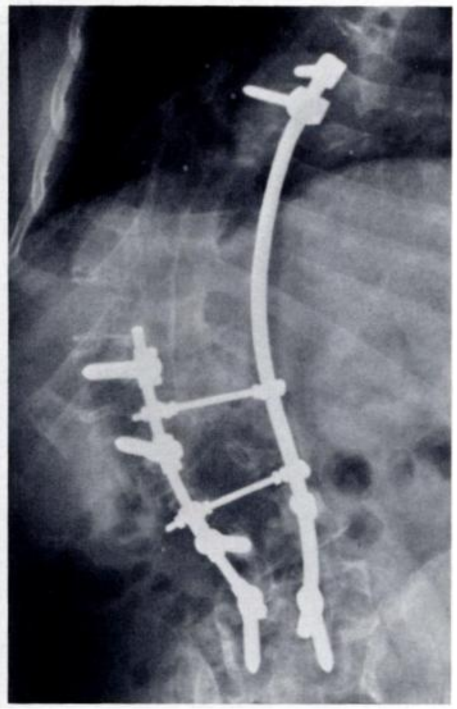

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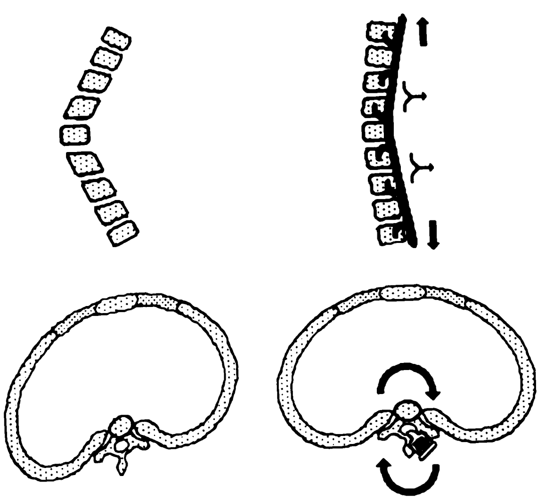
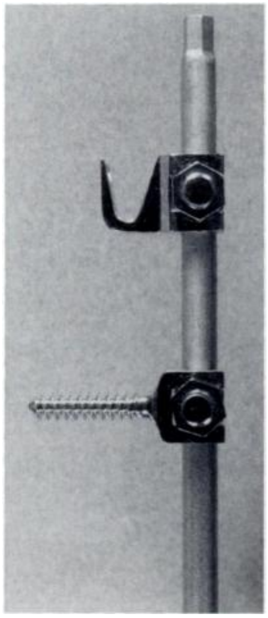


29.

Figures 27–29. **(27a)** Posteroanterior radiograph shows a pair of Cotrel-Dubousset rods with laminar hooks used in the treatment of scoliosis. **(27b)** Lateral radiograph shows the bifid upgoing pedicle hooks (arrow), which are designed to fit around the pedicles. **(28)** AP radiograph shows Cotrel-Dubousset instrumentation, which has been contoured to better accommodate the severe curvature in a patient with scoliosis. The severity of the deformity precluded complete correction. **(29)** Drawing shows the corrective force (arrows) that can be applied to the spine with Cotrel-Dubousset rods.

Cotrel-Dubousset instrumentation (Figs 24–29) was devised in 1980 by two French surgeons who specialized in scoliosis. Cotrel-Dubousset rods are used in pairs connected by a cross-link with four or more laminar hooks or pedicle screws used on each rod. The rods are not threaded but rather have a scored or serrated surface, and the hooks and pedicle screws are held in place with set screws (Fig 24). Both distraction and compression hooks are used. The primary mechanical force they employ in the correction of scoliosis is derotation (Fig 29). The system is so solid that external bracing is rarely needed postoperatively. Cotrel-Dubousset instrumentation can be used to provide stability in cases that do not involve scoliosis. Sometimes the rods are contoured because of an incompletely corrected curvature or to accommodate lordosis or kyphosis.

Figures 30, 31. **(30)** Photograph shows Texas Scottish Rite Hospital hardware. A sublaminar hook is on the top, and a pediatric pedicle screw is on the bottom. Note the increased structural integrity of this system with the nut and bolts compared with that of the small set screw holding on the Cotrel-Dubousset hardware (Fig 24). **(31a)** Lateral radiograph shows Texas Scottish Rite Hospital rods and pedicle screws at the L-3 and L-5 levels. **(31b)** AP radiograph shows a multiple-level laminectomy for disk disease, which resulted in instability necessitating fusion.



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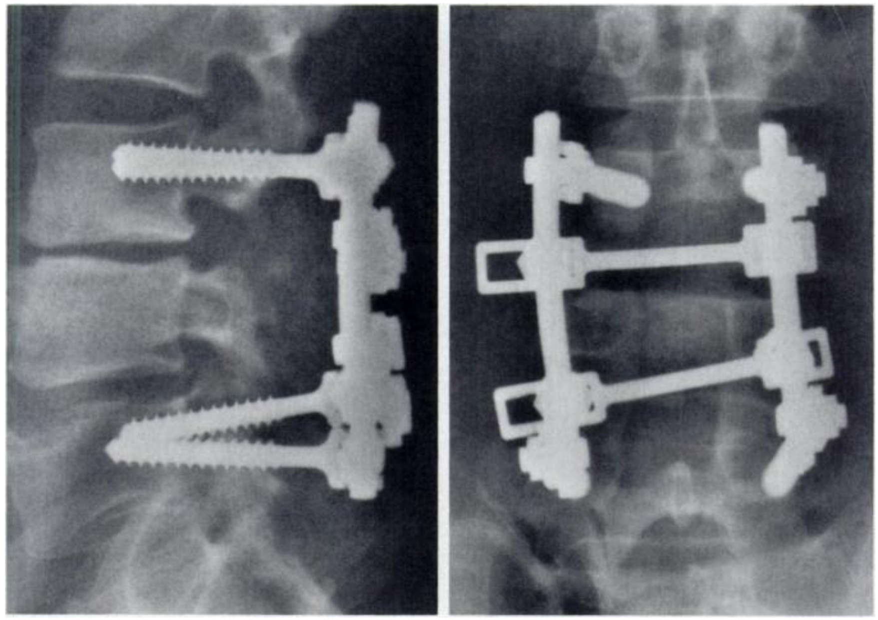
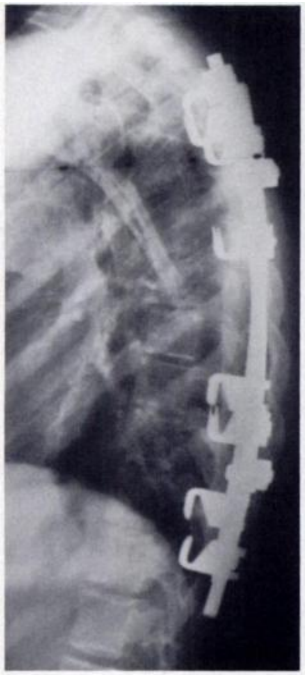


31a. **31b.**

The Texas Scottish Rite Hospital spinal system (Figs 30–34) is similar in principle to Cotrel-Dubousset instrumentation but varies in design. The rods have a roughened surface rather than the serrated surface of Cotrel-Dubousset rods. Eyebolts with large nuts rather than set screws are used to attach the laminar hooks or pedicle screws to the rod (Fig 30). The rods are cut to the desired length, leaving a characteristic bevel on one end. The other end of the rod is hexagonal, allowing the rod to be torqued intraoperatively. In addition to the standard pedicle screws that mount perpendicular to the rod, variable angle pedicle screws that can be mounted to the rod at almost any angle are available. There are various eyebolt configurations available that can be used to provide variable spacing of 0–6 mm between the rod and the screw (Fig 34). These features reduce the need to contour the rods. The Isola system uses paired rods, laminar hooks, and pedicle screws and is very similar to Texas Scottish Rite Hospital hardware.

Figures 32–34. **(32)** Lateral radiograph shows Texas Scottish Rite Hospital hardware used in the treatment of scoliosis in a young female patient. Note the upgoing thoracic pedicle hooks with the bifid tips. The other hooks are thoracic laminar hooks. **(33a)** Lateral radiograph shows Texas Scottish Rite Hospital hardware used to stabilize an L-1 compression fracture. Pedicle screws have been placed into T-10, T-11, L-2, and L-3. Note the partial collapse of L-3. **(33b)** AP radiograph shows eight pedicle screws and two cross-links. **(34a)** Lateral radiograph shows a lumbosacral fusion with bone graft and Texas Scottish Rite Hospital hardware. There are variable-angle pedicle screws in L-4 and S-1 and foraminal cables in the lower sacrum. The variable-angle pedicle screws have a rounded posterior aspect (arrowhead) that differentiates them from the regular pedicle screws. **(34b)** AP radiograph shows spacers used to optimize placement of the pedicle screws (arrows).



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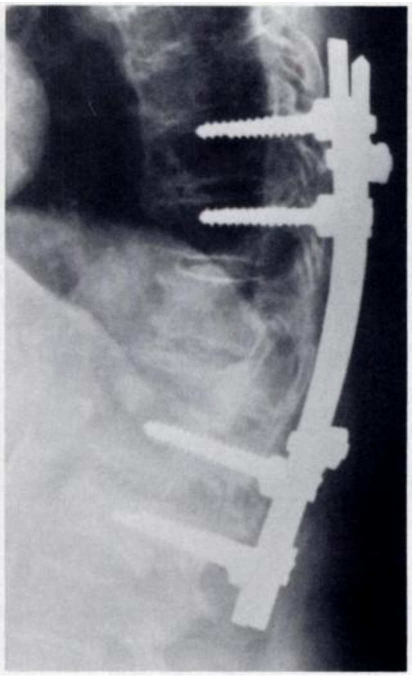

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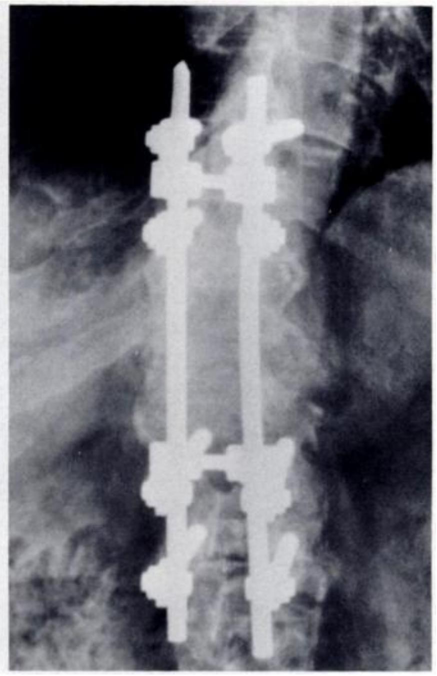

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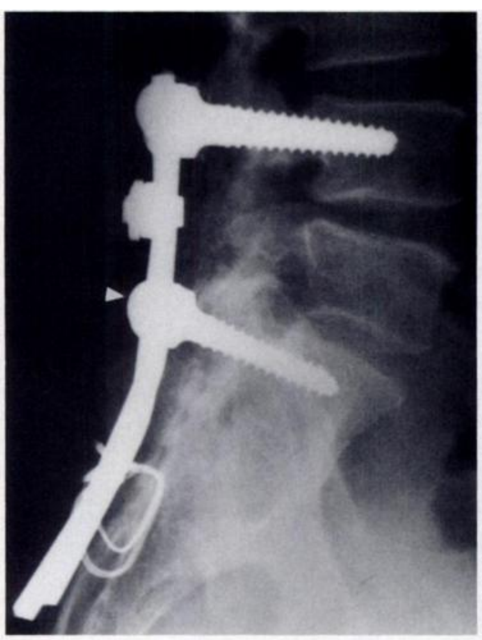

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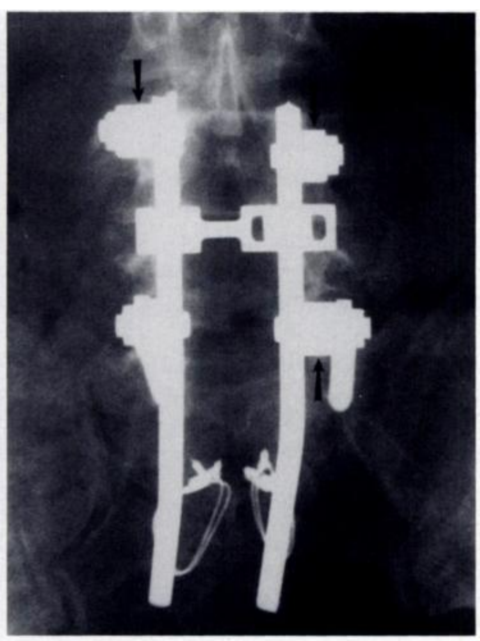
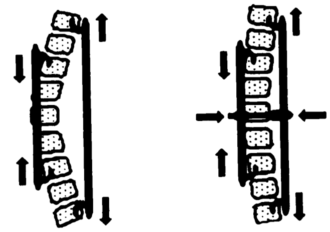


34b.

Figures 35, 36. (35) Drawing in the AP projection shows the extra corrective force (arrows) that can be produced with the addition of a transverse loader to a pair of Harrington distraction and compression rods when used to treat scoliosis. **(36a)** AP radiograph shows Rogozinski plates and hardware used in an L-4 to L-5 fusion. Pedicle screws are offset from the paired rods, which are held together with cross-links. **(36b)** Lateral radiograph shows pedicle screws in L-4 and L-5.



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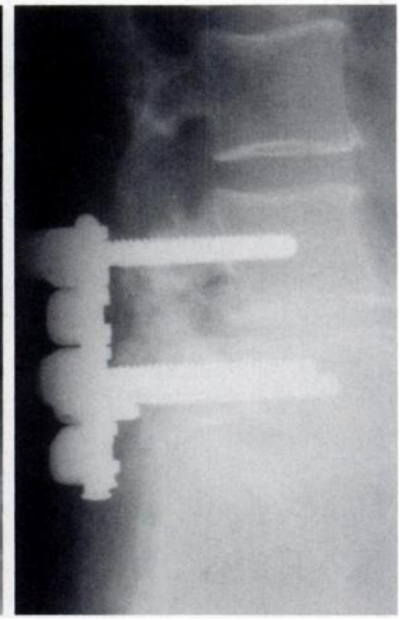
36a.



36b.

Various types of transverse traction devices are designed to attach paired rods together to increase the rigidity and stabilize the construct (Figs 25, 26a, 27a, 28, 31b, 33, 34b). They are also called transverse loaders, transverse traction rods, cross-links, crossbars, transverse couplers, and coupling rods. They consist of smooth or threaded rods, bars, or plates that hook or bolt to the rods. They improve the rigidity of the construct by functioning as a stabilization bridge, increasing the torsional and axial stiffness of the implant (6,13). They are often used between distraction and compression rods to improve the angular correction of scoliosis (Fig 35).

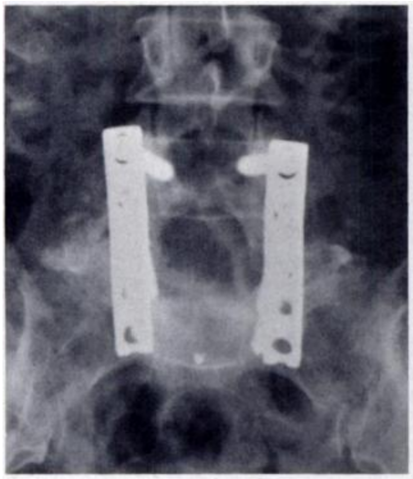
The Rogozinski spinal rod system (Fig 36) is a recently developed hardware system that incorporates hooks and pedicle screws attached to smooth rods, which are cross-linked. The set screws are posteriorly rather than laterally placed, as in the Texas Scottish Rite Hospital system.

• Plates

Plates were originally designed for use on the extremities (14), and some of these have been adapted for use in the spine. Tubular plates and dynamic compression plates have multiple oval holes and a concave contour designed for use on the long bones of the extremities. Dynamic compression plates (Fig 37) are much thicker than tubular plates and are occasionally used in the spine because of their strength.

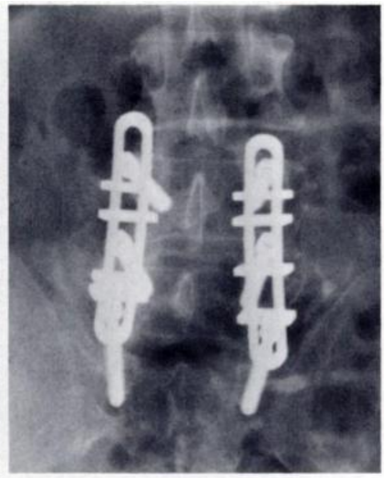
Spinous process plates (Fig 38) were used in the 1940s for lumbosacral fusions. They represent some of the earliest hardware used to stabilize spinal fusions but are no longer used. The plate bolts to the spinous process of the vertebral bodies. Roy-Camille plates are simple straight plates with round holes. They

Figures 37–39. **(37a)** AP radiograph shows a pair of dynamic compression plates used in the lumbosacral spine in a patient with grade II spondylolisthesis who underwent L-4 and L-5 laminectomies. **(37b)** Lateral radiograph shows the thickness of the dynamic compression plate; pedicle screws in L-4, L-5, and S-1; and persistent spondylolisthesis. **(38a)** AP radiograph shows a spinous process plate used for a lumbosacral fusion after a multiple-level diskectomy. **(38b)** Lateral radiograph shows the spinous process attachment. **(39a)** AP radiograph shows Luque plates used for a lumbosacral fusion. **(39b)** Lateral radiograph shows pedicle screws in L-4, L-5, and S-1.



37a.

38a



39a.

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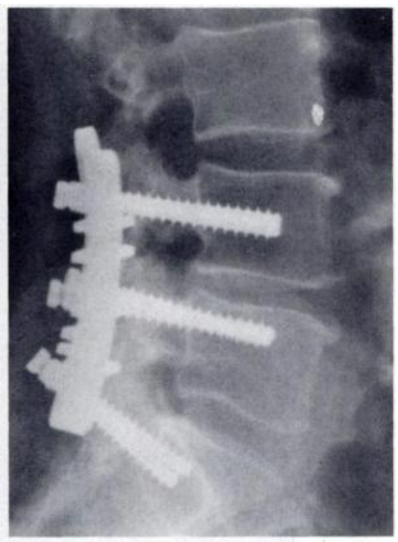
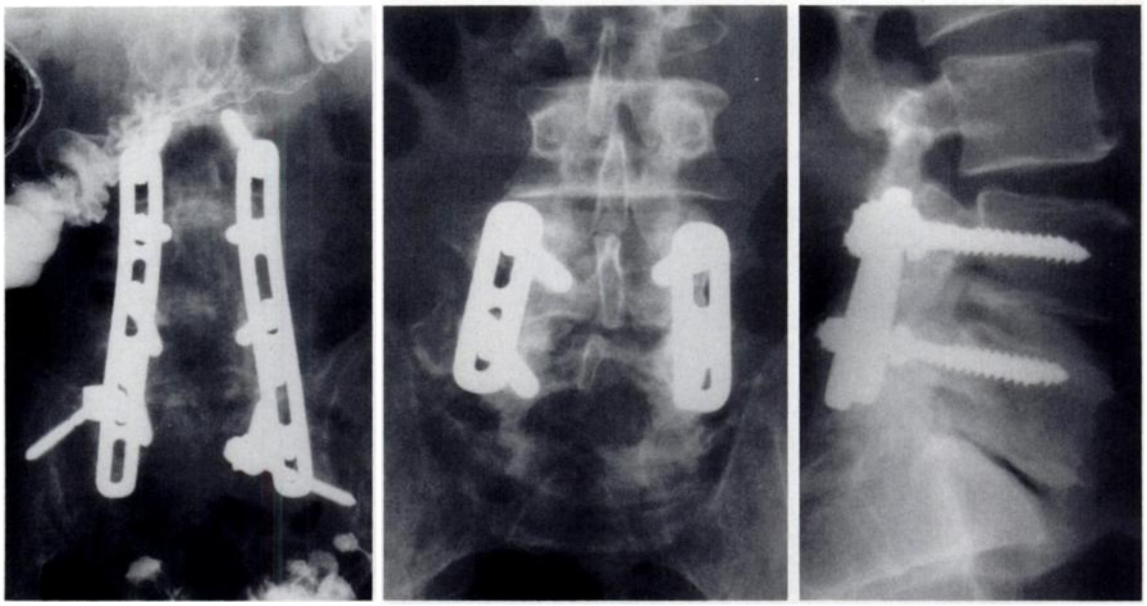
38b.



39b.

were used in a technique developed in the 1970s that involved posteriorly placed plates and pedicle screws.

Luque plates (Fig 39) have long oval holes, through which cannulated screws are passed. Clips encircling the plates prevent the sides from spreading, which would allow the screws to fall through. This technique is not currently used primarily because the plate and screws are not a rigid construct and can move relative to each other.



40. **41a.** **41b.**

Figures 40, 41. **(40)** AP radiograph obtained from a barium enema examination shows a pair of Steffee plates used in a lumbosacral fusion. In this case, locking nuts were not used, and the screws and plates do not form a stable construct. **(41a)** AP radiograph shows two Steffee plates used in an L-4 to L-5 posterior fusion. **(41b)** Lateral radiograph shows Steffee plates.

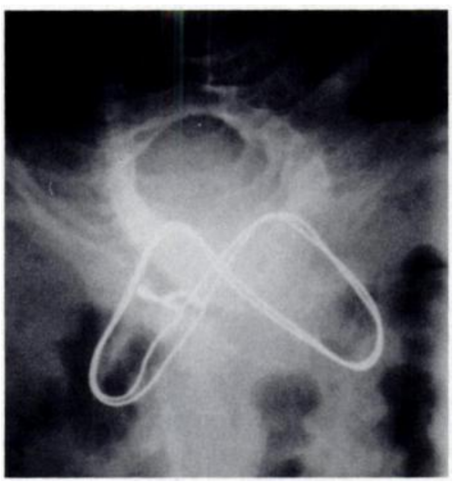


Figure 42. AP radiograph shows figure eight sublaminar wiring with paired wires in a patient with a spinal dysraphism.

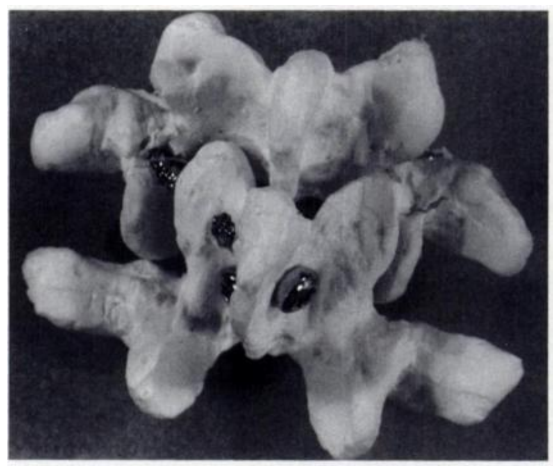
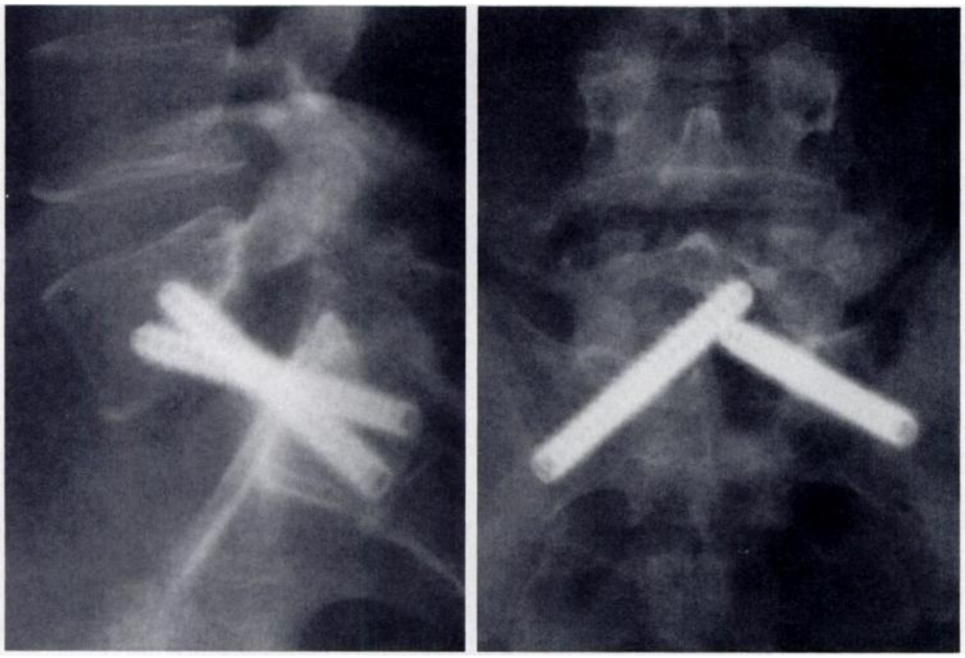


Figure 43. Photograph of a single-level fusion accomplished by passing cancellous screws through the lamina of two adjacent vertebrae.

Steffee plates (Figs 40, 41) are straight plates with long slots that allow the pedicle screws to be placed at any level. In 1986, Steffee devised a technique for stabilizing the plate to the screw by placing a nut on both sides (Fig 41) (15). The pedicle screws are rigidly attached to the plate by a threaded nut on each side. This results in a more stable construct than the Luque plates or Roy-Camille plates. Multiple plates can also be overlapped for more extensive coverage.



a. b.

Figure 44. **(a)** Lateral radiograph of a patient with bilateral spondylolysis at L-5 shows the results of percutaneous pinning of L-5 to S-1 with long interference (hollow) screws. **(b)** AP radiograph shows the posterolateral approach of the screws.

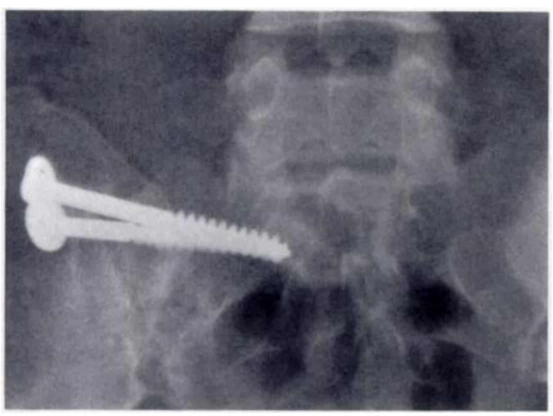


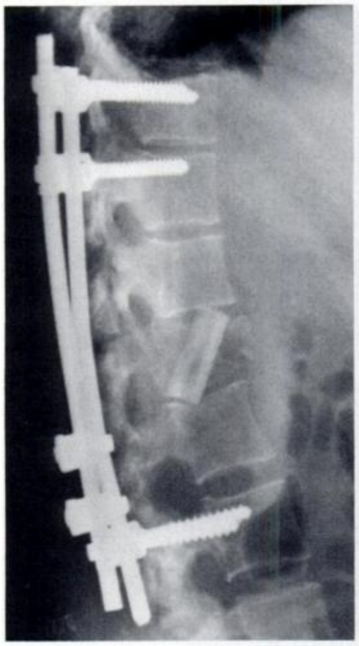
Figure 45. AP radiograph shows a unilateral sacroiliac fusion with two partially threaded cancellous screws and flat washers. (Reprinted, with permission, from reference 14.)

• Miscellaneous Posterior Techniques

Wire is occasionally used as a primary means of fixation (Fig 42) but is generally used to attach rods to the spine or as a supplemental fixation system in conjunction with a rod or plate system.

Translaminar screws (Fig 43) are used in special situations for single-level fusions. This is accomplished by passing cancellous screws through the lamina of two adjacent vertebrae. A new technique of percutaneous screw fixation of L-5 to S-1 has been described as involving long interference screws advanced over guide pins placed with CT guidance (Fig 44) (16). The disk is excised percutaneously, and the screws are placed across the disk level.

Sacroiliac fusions can be performed by simply passing a cancellous screw through the sacroiliac joint (Fig 45). Usually a flat washer is placed over the screw head to increase stability.



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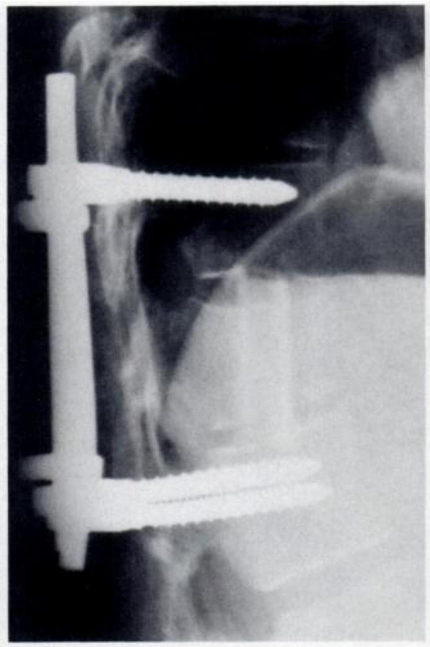

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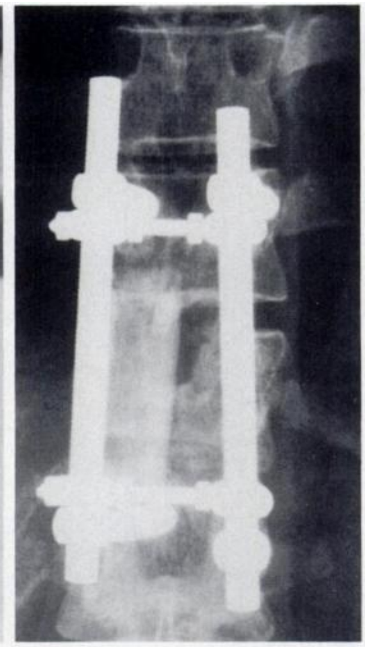
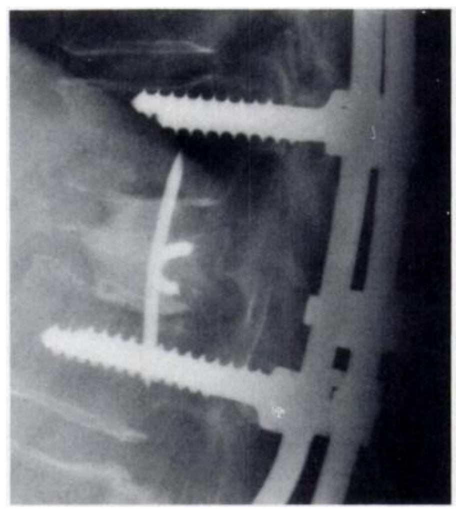


47b.



48.

Figures 46–48. **(46)** Lateral radiograph shows a structural allograft used to treat an L-1 compression burst fracture. Texas Scottish Rite Hospital hardware has been used to stabilize the spine. Pedicle screws are seen in T-10, T-11, and L-3. **(47a)** Lateral radiograph shows a section of fibula used as a structural allograft in a patient with a compression fracture. Two Cotrel-Dubousset rods and four pedicle screws are used to maintain the stability of this three-level fusion. The flexion forces acting on the spine have resulted in a very slight cantilever bending of the lower screws as they exit the bone. **(47b)** AP radiograph shows a partial vertebral body removal with half remaining and the structural allograft well seated in the vertebral body above and below. **(48)** Lateral radiograph shows methylmethacrylate used to maintain vertebral body height after removal. Two Steinman pins are used to prevent migration of the cement. The spine has been stabilized with Texas Scottish Rite Hospital hardware and pedicle screws.

Weiss springs consist of two hooks attached with a spring. They are used posteriorly in pairs, with the hooks placed over and under the lamina to provide compression.

Three-dimensional internal fixation, first reported in 1984 (17), uses pedicle screws as the anchor points. Another device is the Vermont spinal fixator, which consists of a single pedicle screw on each end of a rod; the rods do not contact the lamina. Other devices include the AO and Dick internal spinal fixator. All of these devices allow three-dimensional control of the rod-screw relationship.

External fixation for the spine was devised in 1977 and has the advantage of adjustability and three-dimensional control (6). It can be used to determine if spinal stabilization reduces pain and, therefore, functions as a preoperative diagnostic technique. External spinal skeletal fixation is achieved with Schanz screws anchored into the pedicles and at-

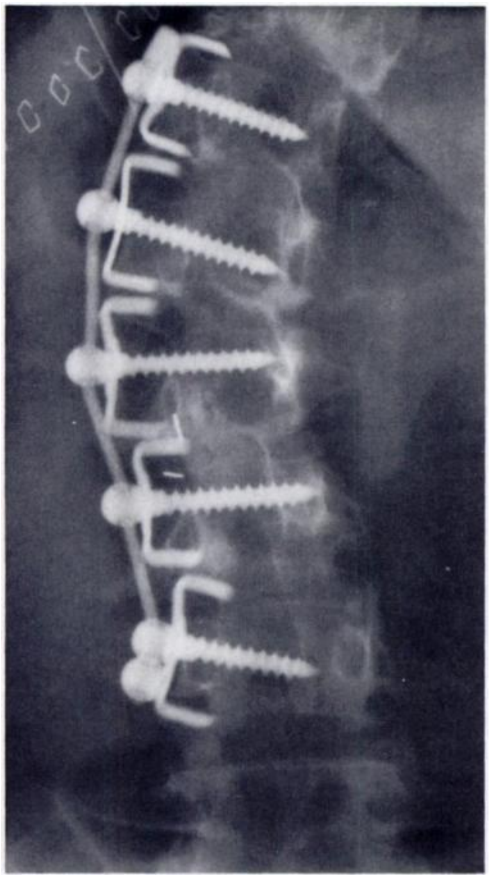


Figure 49. AP radiograph shows a Dwyer device used in the lumbar spine on the convex side of the curve to provide tension.

tached to an external fixator. An external spinal skeletal fixator can be used to achieve distraction or compression. The external components are protected by a corset (18).

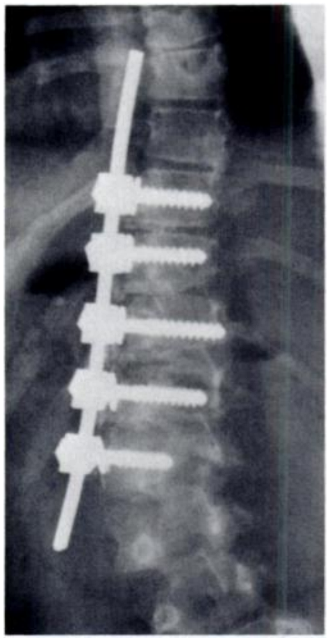
■ ANTERIOR FIXATION

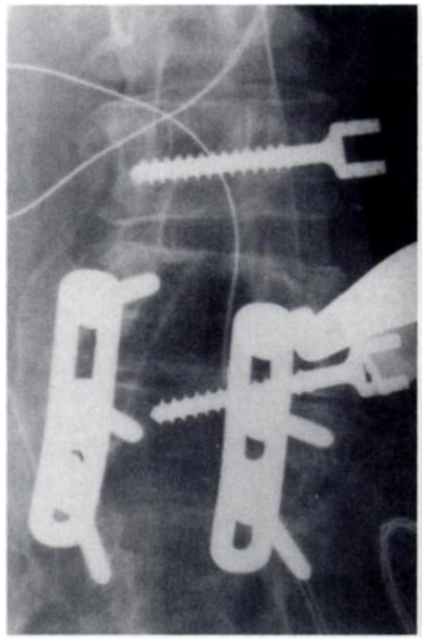
The anterior approach to spinal fixation was first described in 1906 but did not become an accepted procedure until the 1930s, when it was used for the treatment of tuberculosis and spondylolisthesis (19). An anterior approach refers to instrumentation of the anterior spinal column rather than to the surgical exposure, and the hardware is usually attached to the lateral aspect of the vertebral body. An anterior approach is indicated for some neoplasms; infection; failed posterior fusion; high-grade spondylolisthesis; and degenerative conditions including lumbar kyphosis, lumbar scoliosis, and disk disease (19). Anterior decompression is also performed if bone fragments from a vertebral body fracture impinge on the canal.

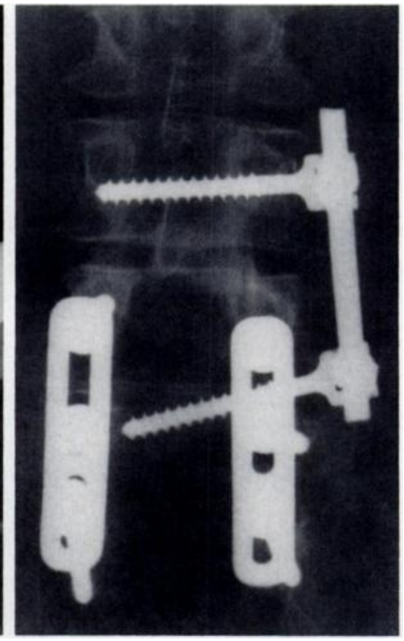
Methylmethacrylate cement and structural allografts are often used in conjunction with rod systems after vertebral body removal (sometimes referred to as corpectomy) or for the treatment of compression fractures (Figs 46–48). Allografts can also be used with anterior fixation devices.

Plates used in anterior fixation include specially designed plates and conventional plates designed for use in the extremities, such as dynamic compression plates of the AO variety. The Anderson plate, introduced in 1988, is rectangular, has multiple holes, and can span several levels. The Syracuse I plate is an I-shaped plate with two holes at each end. These plates maintain position and stability once placed but do not provide a means for reducing the deformity. They are used to treat kyphosis, flat back, pseudarthroses, and failed posterior surgery (19). When used with fusion, the anterior fixation plate places the posterior graft material in compression, which is ideal for healing. The holding power of vertebral body screws is doubled if the contralateral cortex is penetrated (transcortical) (19). The devices should be laterally located, and accurate placement is crucial to avoid damage to the adjacent soft tissues.

In 1964, Dwyer introduced a system that used cables for anterior spinal instrumentation (20). The Dwyer device (Fig 49) is used anterolaterally to correct lordosis and scoliosis. The system consists of screws that are threaded into the vertebral bodies over a staple embedded into the vertebral body. This screw-staple assembly is placed on the convex side of the spine. A braided titanium wire is passed through holes in the screw heads, tightened, and held in place with crimped bands on each end. Usually, the intervertebral disks are removed and a bone graft is placed for an anterior spinal fusion. Dwyer described a high complication rate (19,20), but the device remains useful for the treatment of neuromuscular and degenerative lumbar scoliosis (19).







50. **51a.** **51b.**

Figures 50, 51. **(50)** AP radiograph shows Texas Scottish Rite Hospital hardware used in the anterior column with pedicle-type screws placed directly into the vertebral bodies. The intervertebral disks have been removed, and bone graft material was placed for a T-10 to L-2 anterior fusion. The washers are used in a fashion analogous to the staples in a Dwyer device. The appearance is similar to that of a Zielke device. **(51a)** Intraoperative AP radiograph shows placement of Texas Scottish Rite Hospital pedicle-type screws into the L-3 and L-5 vertebral bodies for an anterior fusion. A patient had previously undergone an attempted posterior fusion with Steffee plates at L-4 to S-1 and had substantial instability at the L-3 to L-4 level. Note that the lower screw passes through the L4-5 disk space. This was noticed intraoperatively but was left in place because of the excellent purchases associated with passing through three cortical layers. **(51b)** AP radiograph shows placement of the rod laterally for an L-3 to L-5 anterior fusion. A bone graft was placed at L3-4.

Zielke modified the Dwyer system in 1975 by replacing the cable with a solid stainless steel rod passed through slotted screw heads (Zielke device) (21). Up to a 10%–15% correction can be obtained at each level (19). It is the device of choice for the correction of lumbar degenerative scoliosis. Both the Dwyer and Zielke devices function as tension devices (placed on the tensile portion of the curve) and place the bone under compression.

Texas Scottish Rite Hospital hardware can be used for anterior fusions. Generally, pedicle screws are inserted directly into the lateral aspect of the vertebral body and are connected with a single rod (Figs 50, 51). Staples or washers are usually placed over the screw to provide stability.

Other anterior devices include the Kaneda device described in 1984, which consists of two curved vertebral plates with staples attached to the vertebral body with screws. The plates are connected by two threaded rods that attach to the screw heads with nuts (22). The Dunn device is similar, but its use was discontinued due to reports of vascular injuries (19). The Slot-Zielke device consists of a rod and Zielke screws and is used for the treatment of kyphosis. The Kostuik-Harrington system uses Kostuik spinal screws placed in the vertebral bodies with Harrington distraction rods. The screws have large washer-like heads. A second Harrington compression rod is placed posteriorly. This is used to treat kyphosis and the flat back syndrome.

■ CONCLUSION

Spinal surgery practiced by both neurosurgeons and orthopedists is a complex and dynamic subspecialty. The radiologist is faced with continual changes in both surgical technique and instrumentation. To properly evaluate radiographic and special imaging studies, it is necessary for the radiologist to have a working knowledge of the devices used in these patients and the biomechanical principles that direct their use. In this article and the preceding one (1), we have attempted to provide a current overview of spinal surgical techniques and a reasonably complete atlas and reference of spinal fixation devices along with an explanation of their function. Radiologists are encouraged to work with their surgical colleagues to become more familiar with the techniques in use at their institution.

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