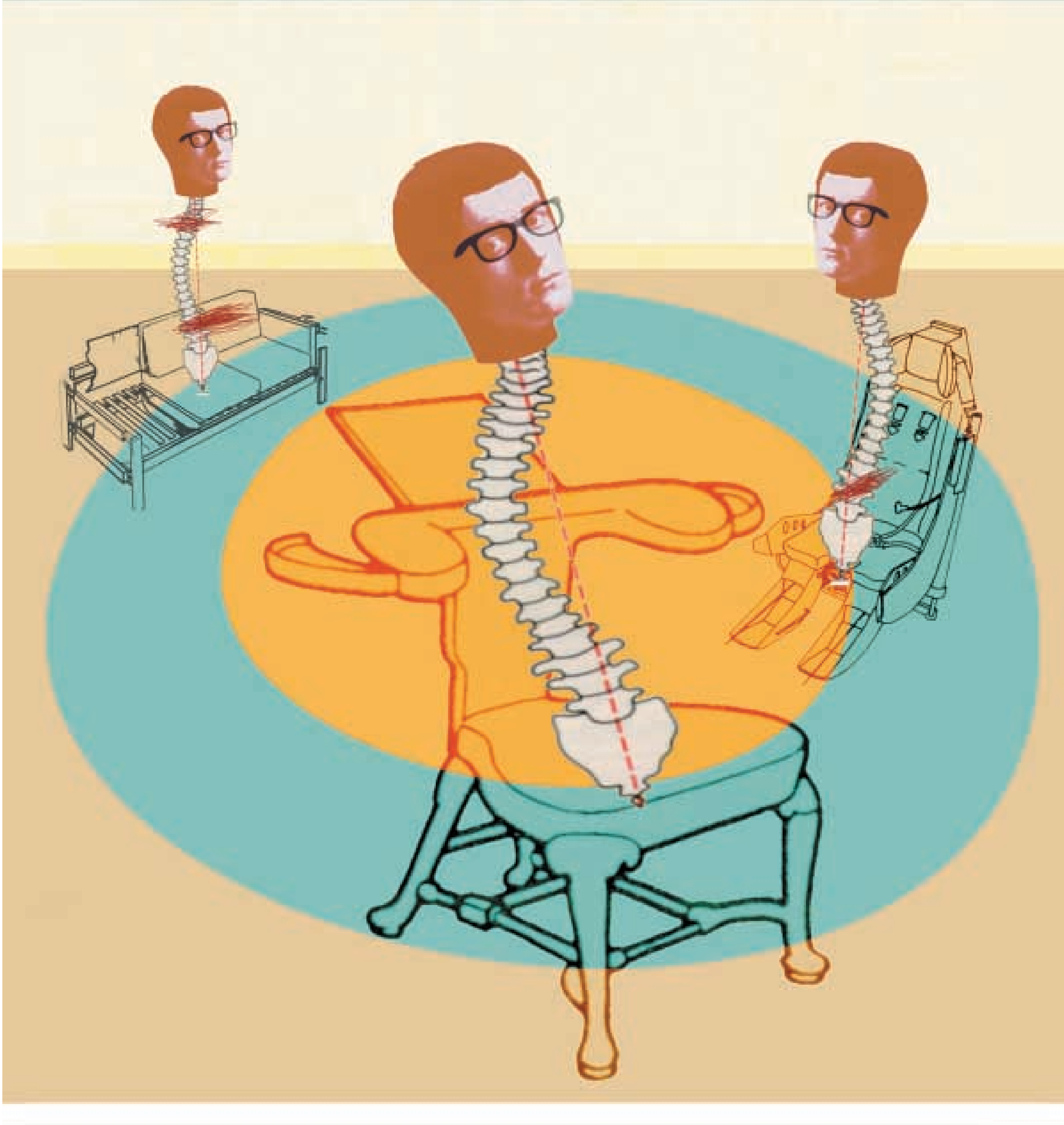
Posterior



spinal SURGERY
20th century advances

By Jeff Cortese, CST

Although successful spinal fusion was reported as early as 1911, the procedure wasn't more fully developed until the 1950s when the Harrington rod became available. As Harrington's spinal instrumentation system was advanced (Figure 1), others—such as Moe, Edwards (Figure 2), Jacobs, and Luque—modified the technique to expand its clinical applications. Around the same time, segmental fixation was also being developed. The Cotrel-Debousset system, Texas Scottish Rite spinal system, and posterior plating systems added functionality. "Posterior Spinal Surgery: From Ancient Egypt to the Late 20th Century," published in the November 2000 issue of *The Surgical Technologist,* covered in detail these early developments of spinal fusion.

In 1944, D King began using the pedicle as a means of spinal fixation. By 1959, Boucher had achieved success in passing screws through the lamina and pedicle into the vertebral body. These two developments allowed the surgeon to perform aggressive decompressions of the spine, while stabilizing a limited number of spinal segments and preserving the normal contours of the spine. This article focuses on the considerable advances made through screw systems and documents recent developments in spinal fusion.

Variable screw placement system

In 1986, Arthur D Steffee introduced the variable screw placement system (VSP) as a means of transpedicular fixation of the unstable spine. He described the efficacy of this system in patients suffering from spinal instability, severe back pain unresponsive to conservative treatment, and patients with back pain relieved by immobilization.[34] In his earliest article in VSP plating, he described the concept of the "force nucleus," the junction of the pedicle, superior and inferior facets, the pars, transverse process and lamina, a channel where all forces posteriorly can be transmitted anteriorly through the pedicle to the anterior column of the spine. The functional importance of the pedicle's anatomic location is further enforced by the proximity of the lumbar multifidus and longissimus attachments, both important to segmental movements of the spine.[33]

Steffee's early attempt at fixation of the "force nucleus" consisted of an AO neutralization plate and cancellous bone screws, but he soon discovered the lack of flexibility between the fixed circular plate hole and the hex head of the cancellous screw.[33] This led to the development of the variable screw placement system.

The VSP system, marketed by DePuy Acromed, consists of two bilaterally placed plates with nested slots, allowing precise placement of specifically designed screws at any angle necessary for rigid fixation.[34] The screw consists of a long cancellous threaded portion that enters the pedicle and a machined-threaded portion on its shank with an integrated hex nut between both portions assisting in level placement of the slotted plates.

The screw lengths vary from 16 mm to 55 mm, with screw diameters of 4.75, 5.50, 6.25, 7.0, 7.75, and 8.50 mm. The material for the hardware can be manufactured from either stainless steel or lighter-weight titanium. Three different plate-spacer washers are used between the hex head of the cancellous portion of the screws to achieve level metal-to-metal contact between the plate and screw shank.

A VSP tapered nut is used to secure the plate to the pedicle screw, and a VSP lock nut is then used on all VSP screws to secure the entire fixation device. The VSP instruments consist of a VSP T-handle screw wrench with a 3.18-mm hex socket for all VSP screws, a VSP T-handle nut wrench with a 9.5-mm hex socket for tapered nuts, and an 8-mm hex socket for locking nuts. The set also includes a VSP screw alignment bar and rod, a VSP pedicle probe, a VSP aluminum template set, a VSP sounding probe, and a VSP bone tap.

Wilste system

The initial use of the Wiltse system in humans started on May 24, 1984, at the Long Beach Memorial Hospital. Twenty other centers in the United States have since started using this system.[36] Pedicle screw fixation has provided the spinal surgeon with a powerful and versatile new tool. Rates of pseudoarthrosis in the lumbosacral spine continue to be high, particularly after the surgical removal of all or part of the facet joints. The Wiltse pedicle internal fixation system reestablishes the continuity of the facet joints. The fusion has been increased to 91.7% in the Phase II FDA study.[38]

The Wiltse pedicle system offers a reliable point of fixation to the vertebra. Pedicle screw fixation does not rely upon distraction, compression, or the presence of the posterior elements for fixation. By using some special instruments, pedicle screws allow the surgeon to exert distraction or compression forces as needed.

The pedicle screw system allows the surgeon to place the pedicle screws in the most appropriate position and then interconnect the screws by a malleable stainless-steel rod and a unique saddle-clamp assembly. In order to create a template, an aluminum, hand-malleable mastering rod is used to create a model. Using this mater, an exact stainless-steel duplicate can be fabricated. For this, a variety of bending instruments has been developed. In the case of particularly severe deformity over many levels, a major bending system is available that allows one to accurately contour the necessary rods.

These stainless steel rods are placed into the saddle-clamp assembly. A unique lock washer attached to the top saddle prevents loosening and allows the surgeon to use a single nut, thereby lowering the profile of the assembly (Figure 3 and 4).

The Vermont spinal fixator

The use of the pedicle as a method for spinal implant attachment became a major advance in spine surgery. It provides a grip on the vertebra that resists loads of any type. Placement of a truly transpedicular screw was first reported by Harrington and Tullos in 1969, but was first developed as a practical method by Roy-Camille.[14] It was Martin Krag's experience with the Roy-Camille system in 1981 that led to the idea of the internal fixation device, later called the Vermont spinal fixator (VSF). This was further stimulated by a meeting in 1981 with Magerl and Schlapfer concerning their work on an external spinal fixator.[24,32]

At the time, there were no published descriptions of any other transpedicular system, not to mention the basic anatomic and biomechanical research. This prompted a series of anatomic and biomechanical studies that brought about the exact specifications for the VSF and clinical use in July 1986.

AO fixation of the posterior spine

The use of the narrow, dynamic compression plate (DCP) in the treatment of thoracic and lumbar spine fractures was briefly described by the AO group in their *Manual of Internal Fixation*.[26] They cited the technique of Roy-Camille for performing internal fixation with pedicle screw plating.[31] Instead of using his round-hole plates, however, they advocated narrow DCPs, which allow the screws to be angled through the holes in any direction.

The DCP was developed by the AO group in 1965.[35] They touted the DCP as representing an improvement on the traditional round-hole plate because of the special geometry of the screw holes that allows for two unique advantages.[31] First, axial compression may be achieved without the use of a tension device if a special offset-drill guide is used. This is not applicable to the posterior transpedicular placement of these plates, but is useful for compression of the bone graft after an anterior corpectomy and instrumentation with the broad 4.5 mm DCP.

Second, it is possible to angle the screws through the holes in any direction desired. This is very significant for posterior plating since the screws may be angled in an unlimited direction to properly enter the vertebral pedicles. The magnitude of the angulation is 25° longitudinally, in each direction parallel to the plate axis, and 7° laterally, perpendicular to the long axis.

In a round-hole configuration, the head is seated in the hole when the screw is perpendicular to the axis of the plate. If the screw is inserted obliquely, a torsional force occurs at the head in its perpendicular position. The torsional force is transmitted as a movement to the screw threads, causing asymmetric forces at the thread-bone interface. These asymmetric forces increase as the movement arm (screw length) increases and may lead to stress risers. The advantage of placing cancellous screws oblique to the axis of the plate is important when the hole does not lie exactly over the center of the pedicle. In a fixed-hole system, this will occasionally occur. Oblique orientation of the screw through the plate hole into the pedicle, without a concomitant torsional movement experienced by the screw tip in the vertebral body, is optimal. The DCP's are named for the diameter of the outer thread of the cortical screw that corresponds to that particular plate. The 4.5 mm cortical screw has an 8.0 mm head that interfaces with the 4.5-mm DCP screw hole.

The 6.5-mm cancellous screw also has an 8.0 mm head and is used with the 4.5 mm DCP. The 4.5 mm DCP is made in broad and narrow fash-

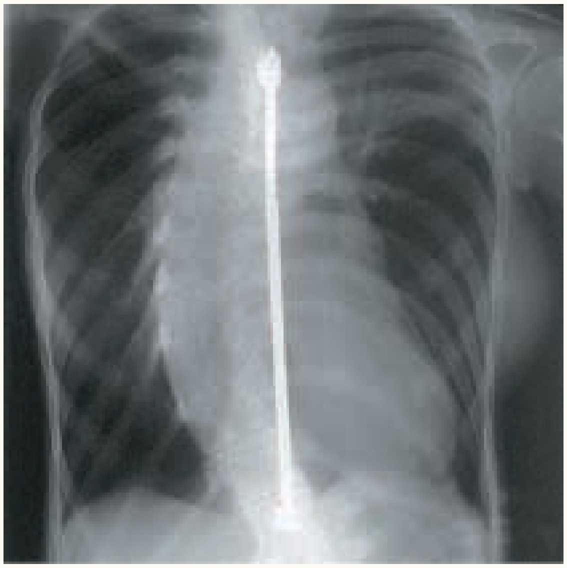


FIGURE 1

A Harrington rod and bone graft are shown bridging the spine of a patient with thoracic scoliosis.

ion. The broad 4.5 mm DCP has the holes staggered about the long axis of the plate to avoid placing the screws in the same plane. This is advantageous in a long bone and the anterior vertebral body because the chance of fracture occurring through the plane of the screws is decreased. The narrow DCP is characterized by all of the holes being in line with the long axis of the plate and is the type applicable to pedicle screw plating. The screws are named by the outside diameter of their thread. The 6.5 mm cancellous screw has a 3.0 mm core and a 2.75 mm pitch.

It is imperative when using the 6.5-mm cancellous screw, that the fully threaded modification is used. This provides thread fixation in

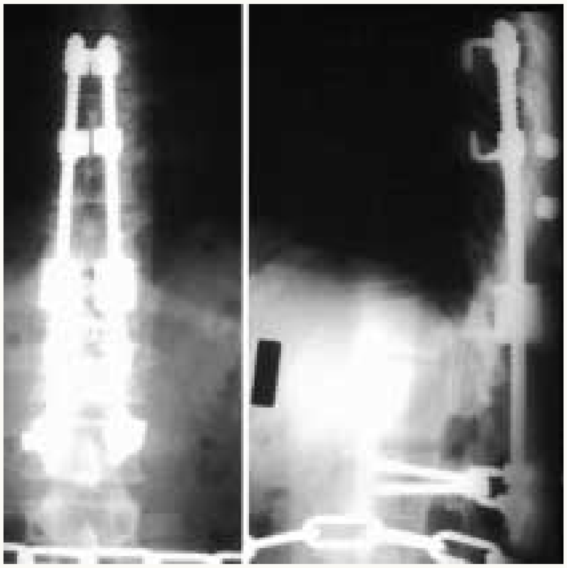


FIGURE 2

Bilateral Edwards rods were used to bridge a spinal fracture.

the pedicle, which is the strongest region for fixation of the vertebral complex.[32] These full-threaded cancellous screw modifications are generally not included in the standard large-fragment set and must be ordered separately.

A plate may be named by its anatomic and biomechanical characteristics. The anatomic properties of a plate are described by its material configuration, such as T, round hole, or a slotted plate. The biomechanical characteristics are determined by the functional manner in which the plate is operating, such as a compression, tension band, or neutralization plate.

The function of a specific plate is not necessarily governed by its anatomic configuration.[4] For example, a round-hole plate can biomechanically function as a static compression, tension band, or neutralization plate, depending upon the manner in which it is employed.

Unfortunately, the DCP is named by one of its possible biomechanical functions rather than by its anatomic characteristics. It is thus sometimes confusing when describing the use of this plate. Even if the screw is placed centrally rather than eccentrically through the plate hole (thereby not utilizing the self-compressing function), the plate is called a dynamic compression plate. A more appropriate name would identify the plate by its semicylindrical screw holes for the others.[4]

The bending strength of a screw is proportional to the effective thread diameter. The effective thread diameter is equal to the outside thread diameter minus the core diameter.[26] The 4.5 mm cortical screw is fully threaded and has a core diameter of 3.0 mm and a 1.75 mm pitch. Both screws have a head diameter of 8.0 mm and uses the 3.5 mm hexagonal screwdriver.

The 3.2 mm drill bit corresponds to both the 4.5 mm cortical and the 6.5 mm cancellous screws, since the core diameters are equal. The two screws have equal bending strength, but the 6.5 mm cancellous has a stronger pullout strength.

The AO instrumentation described has proven to be a valuable adjunct in attaining fusion of the lumbar spine. The implants are readily available in all centers equipped with AO large-fragment sets. This is an extremely demanding procedure, however, and if used, must be limited to those surgeons who have specific training in transpedicular fixation and extensive experience in spinal surgery.

Although popular in Europe for many years, a wave of enthusiasm for transpedicular fixation of the spine swept through North America during the 1980s. While technically demanding, the advantages of pedicle screw fixation have become readily apparent to a growing number of surgeons.

It is a technique that allows the surgeon to thoroughly decompress the neural elements by the joints and pars articularis, if necessary. At the same time, immediate stability to the spine via transpedicular screw fixation is provided.[12] The earlier transpedicular fixation systems are primarily of the plate type and are satisfactory for some patients.[15,20] However, difficulty is encountered when contouring is required to accommodate both sagittal (lordosis) and coronal (scoliosis) curvatures. In addition, the transverse dimension of the available plates limits the space available for the application of a bone graft.

Transpedicular external fixation has been designed and used on fractures and for temporary fixation as a diagnostic test for lumbosacral instability.[24] However, its problems—protrusion of the device, pin-tract infection, and potential for accidental penetration of the screw through the anterior cortex of the vertebral body—make the device very unappealing.[18]

The Puno-Winter-Byrd system

The problems described led, in 1984, to the development of a new pedicle screw system.[27] The Puno-Winter-Byrd (PWB) pedicle screw system is a rod-and-screw transpedicular fixation device designed to provide immediate mechanical stability to the instrumented spinal segments while bony fusion is taking place. Like any spinal instrumentation system, it is used as an adjunct to the surgical fusion technique. The primary goal of surgery is to produce a solid fusion, so the device should not be used as a substitute for meticulous technique in the arthrodesis procedure.

The purpose of all spinal fixation systems is to provide an optimum degree of stability to the instrumented spine in order to enhance the success rate for obtaining a solid fusion. However, there is no data available to prove the optimum degree of rigidity. Historically, spinal fixation systems have had total rigidity as their goal, with the thought that this would best enhance solid fusion. On the other hand, experience with long-bone fractures shows that rigidly fixed fractures often produce less-abundant calluses than those treated in a cast, which allow some degree of fracture motion. This would suggest that total rigid spinal fixation may not be necessary to provide the optimum milieu for a solid fusion.[27]

In addition, totally rigid pedicle-screw fixation of the lumbar spine can create potential problems, such as loosening at the bone-screw interface, especially in osteopenic bone, screw breakage, and stress shielding.[25] With these problems in mind, the PWB pedicle screw system was developed to allow for micro motion between the screw and rod via the use of a special coupling device. The micro motion produces a "shock absorber" effect to decrease the stress concentration at both the bone-screw interface and the screw-rod interface, which then enhances load sharing between the device and the bone.

Finally, the PWB pedicle screw system was designed to simplify implantation. The system has only six components and utilizes standard implantation techniques. As the PWB system evolved, several design changes were made to satisfy the aforementioned criteria. The final implant system resulted from five prototype designs. While there are several transpedicular systems available, they generally fall into two broad categories. They are either of the screw-and-plate design or the screw-and-rod design.

There are features of the PWB transpedicular spinal system that further enhances its function. Foremost of these is the fact that the screw and seat are two separate pieces, providing the micro motion necessary to decrease stress concentration at the screw-seat junction, thereby minimizing failure. In addition, the surgeon is able to compensate for the various small differences in pedicle direction from segment to segment without sacrificing seat alignment. This simplifies the ease of rod placement. The availability of four seat sizes allows careful tailoring of the instrumentation construct for each individual case despite the natural variations occurring from patient to patient. The PWB transpedicular system is easily implantable and provides the meticulous surgeon a new pedicle screw system that securely immobilizes the spine.

External spinal fixator

The development of the "fixateur interne" has its origins in the developments by Friedrich P Magerl. Since 1977, Magerl has been working on the applications of external spinal skeletal fixator (ESSF).[24] The ESSF system consists of obtaining segmental spine fixation through posteriorly placed pedicle screws held rigidly fixated by an external apparatus. He utilized 5 mm Schanz screws placed into the pedicles through either an open or closed technique.

Magerl and the Swiss Research Institute Laboratory for Experimental Surgery in Davos developed a connecting device to obtain rigid external fixation of the screws.[24] Magerl reported using the ESSF for fractures and infections. His results were very encouraging, but it was inconvenient for the patient to have an external fixation apparatus for weeks at a time.

With the ESSF, Magerl launched a new dimension is spinal instrumentation—reduction and restoration of anatomy while fusing only a limited number of segments—which has great potential. Also, he tried to achieve optimal stability for immediate mobilization with minimal external support. Based on the these ideas, W Dick modified the ESSF. The fixateur interne, as developed by Dick, consists of long 5 mm Schanz screws that are inserted posteriorly through the pedicles into the vertebral bodies.

The connector is a 7 mm threaded longitudinal rod with flat sides and clamps that are mobile in every direction, and it is completely implanted using the posterior approach. The clamps hold the Schanz screw; the threaded rod permits distraction or compression. Through the long lever arm of the Schanz screws and moveable clamps, it is possible to apply lordotic or kyphotic forces. The configuration can then be fixed in the desired position with nuts.

The Edwards modular system

The Edwards Modular System has evolved from a 12-year effort to sequentially overcome the problems and limitations faced by surgeons who seek to reconstruct the deformed or unstable spine.[10] It combines the contributions of Paul Harrington and Ramon Roy-Camille and adds the concept of adjustable transverse control in all dimensions. In the late 1970s, Charles Edwards, MD, concentrated on the surgical reconstruction of the injured spine.[10] From this experience, it became apparent that, for optimal results, a surgeon should first determine the primary vector(s) of injury from radiographs and then use instrumentation to directly counteract these deforming forces. Since most thoracolumbar fractures were caused by compression, flexion, and rotational forces, instrumentation was needed that could generate distraction and extension, and provide rotational control.

Harrington rods contributed the necessary distraction, but, even when contoured, provided only minimal extension and virtually no rotational control, resulting in frequent hook dislodgment. To provide the necessary active lordosis and rotational control, rod-sleeve spacers and the rod-sleeve method were developed to improve reduction and provide "indirect compression" of flexion-compression injuries.

The rod-sleeve method consistently yielded anatomic alignment, but laminar edge reabsorption with occasional hook dislodgment still occurred. These hook interface problems led to the design of an L-shaped anatomic hook in 1982. The L design increased hook-laminar contact area over C-shaped hooks to reduce laminar reabsorption and hook dislodgment.

The next problem was the inability to anchor rods directly to the sacrum to apply compression or distraction forces across the lumbosacral junction. The Sacral Fixation Device was developed in 1983 to overcome this limitation.[10] This device introduced two new capabilities: 1) the ability to attach spinal rods, which could be ratcheted in either compression or distraction, directly to the sacrum with screws; and 2) the ability to attach to proximal vertebrate with either laminar hooks or pedicle screws, designed for sacral alar or lumbar pedicle fixation.[10]

The capability of secure fixation in compression across the lumbosacral junction improved the in situ fusion rate and effectiveness in treating low lumbar nonunion. However, the systems still lacked the versatility needed to correct most lumbar deformities without anterior or transspinal releases and forced manipulation. In an effort to achieve more correction of deformity with less surgery, Edwards sought to incorporate intraoperative stress relaxation. However, this required instrumentation with adjustability in all planes of motion. This requirement was fulfilled with the development of adjustable pedicle connectors in 1985. Connectors served as linkages between spinal screws and rods. They could be shortened or lengthened and positioned to translate individual vertebrate in any direction. Combining adjustable connectors with bi-directional ratcheting rods made it possible to gradually apply corrective forces and maintain stable fixation in all dimensions.

During the past five years, Edwards and his associates have focused on the development of surgical procedures that incorporate stress-relaxation to improve correction of kyphosis, spondylolisthesis, scoliosis, and other thoracic and lumbar deformities.[10] As the scope of surgery expanded, Edwards saw the need to enhance the overall stiffness of the final construct in selected cases. This need was met with the recent addition of adjustable-rod crosslinks.

Over the past decade, Edwards modular instrumentation has become a comprehensive posterior spinal system composed of six basic components:

1. Anatomic hooks for attachment to thoracic or lumbar lamina.
2. Screws for secure fixation to the sacrum or lumbar pedicles.
3. Bi-directional ratcheted universal rods for axial control.
4. Various-sized rod-sleeves as fixed transverse spacers.
5. Pedicle connectors for adjustable transverse control in all directions.
6. Adjustable-rod crosslinks for control of relative rod position and instrumentation stiffness.

These six components or "modules" can be assembled into a variety of constructs, depending on the biomechanical needs of each case. For example, the compression construct is designed to provide both stabilization and physiologic axial loading to promote bony union. Other constructs are designed to apply optimum corrective forces over time for greater reduction or deformity with less invasive surgery than required in the past. These include the rod-sleeve construct for thoracolumbar fractures, the distraction- lordosis (D-L) construct for lower lumbar fractures and degenerative listhesis, the kyphoreduction construct, spondylo construct, and various scoliosis constructs. Extensive studies of these constructs have demonstrated improved clinical results.

Arthrodesis of long segments of the spine to a sacrum may be necessary for a variety of pathologic conditions and indications. The surgery may be necessary for patients who have had prior surgery, had failure of a fusion, or had degeneration above the area of prior fusion. Revision of prior surgeries, in which distraction instrumentation was used resulting in flat-back deformity, remains a problem. A better understanding of the biomechanical stresses placed on the fixation devices and the bone-implant interface has resulted in the development of improved techniques of fixation in the lower lumbar spine and the sacrum. This fixation always requires multiple levels of segmental spinal instrumentation. The type of instrumentation depends on the design of fixation, whether it is wire, hook, or screw, and the bone into which it is placed.

FIGURE 3

In this patient with spinal stenosis, bilateral posterior spinal rods bridge L4, L5 and S1 (anteroposterior view following a laminectomy).

Conclusion

The surgeon needs to understand the limitation of both the instrumentation and the bone prior to proceeding with this demanding surgery. Why is so much emphasis placed on instrumentation? A tendency exists to not pay enough attention to the most important part of the operation. The surgery is always an arthrodesis and an attempt to place the spine in a stable and balanced position. Meticulous surgical techniques for arthrodesis are required, or failure is likely to occur. If the spine is placed in an unbalanced situation and the fusion area is placed under tension, failure of fusion and, subsequently, of the instrumentation will occur. The understanding of these concepts and principles is more critical to the success of this type of surgery than the specific instrumentation used. Instrumentation will continue to change using different metallurgy and designs, but these principles and the goal of obtaining a solid arthrodesis and a balanced spine will never change.

FIGURE 4

A lateral view of the rods in Figure 3. The small metal cage contains bone graft material to promote osseous fusion at this site.

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