Zindrick et al concluded that these data confirmed previous studies that pedicle fixation can be used in adolescents in the lumbar spine before other areas of the spine. In older adolescents the thoracolumbar spine may be large enough for pedicle fixation. In patients with spinal deformities the pedicles, especially the concave pedicles, often are deformed, and great care must be taken in insertion of any pedicle fixation.

2.1 IDENTIFYING PEDICLES

Various methods have been described for identifying the pedicle and placing the pedicle screw, but basic steps include (1) clearing the soft tissue, (2) exposing the cancellous bone of the pedicle canal by decortication at the intersection of the base of the facet and the middle of the transverse process, (3) probing the pedicle, (4) verifying the four walls of the pedicle canal by probing or obtaining roentgenographic confirmation, (5) tapping the pedicle, and (6) placing the screw. In the lumbar spine, pedicle screws are commonly inserted using anatomical landmarks, and confirmatory roentgenograms are obtained. Because of the deformed pedicles...
associated with scoliosis, many surgeons use fluoroscopic guidance. Although Suk et al. used anatomical landmarks and confirmed the position of guide pins with plain roentgenograms, most surgeons believe that because of the tight confines of the pedicle in the thoracic spine, intraoperative fluoroscopy is indicated. When multiple thoracic pedicle screws are used, fluoroscopy time can be quite significant. Polly found that the average fluoroscopy time per thoracic screw was about 10 seconds. Frameless stereotactic technology is available that allows three-dimensional navigation but requires time-consuming segmental registration and preoperative CT data. Investigations are currently under way using stereotactic technology combined with fluoroscopy (fluoroNav, Medtronic Sofamor Danek, Inc., Memphis). This technology has the potential to greatly diminish radiation exposure to both the surgeon and the patient and to allow spontaneous viewing of instrument positions in as many projections as desired.

2.2 ENTRY POINTS & DIFFERENT TECHNIQUES

In the original technique described by Roy-Camille, the entrance point for screw insertion was situated in the intersection between a vertical line passing through the middle of the inferior facet and a transverse line passing through the middle of the transverse process. The direction of the screw was
perpendicular to the posterior plane of the vertebra and straight forward. No
detailed information concerning violations of the thoracic pedicle associated
with screw placement was documented by Roy-Camille. Vaccaro et al were
the first to evaluate the feasibility of the Roy Camille technique of pedicle
screw placement in the thoracic spine. They inserted 90 screws into the
thoracic pedicles from T4 to T12 in five cadavers, and noted that the 37 (41%)
screws penetrated the lateral cortex; Twenty-one penetrated the medial
cortex of the pedicle and 16 the inferior cortex. The results from another study
shows that a total of 52 (55%) of 95 screws placed by the Roy-Camille
technique violated the pedicle walls. The incidence of pedicle violation
derived from the current data was higher than that from the data of Vaccaro
et al. This may be attributed to the differences in the use of the thoracic
levels. A higher incidence of pedicle violation could be expected if screws
are placed into the upper thoracic spine. This is because of increased pedicle
medial inclination and its variation, although T1 and T2 pedicles are larger
than T4–T11.

Screw placement using the Roy-Camille technique was associated with
higher percentages of violation of the lateral (31.6%) and inferior (11.6%) walls
of the pedicle than those placed with the open-lamina technique.
Anatomically, the pedicles anteromedial inclination in the transverse plane
varies from cephalad to caudal. In general, this angle decreases gradually from T1 to T12. In the lower thoracic levels, screw placement with a straightforward direction may be safe. However, in the middle and upper thoracic levels, this technique would have a higher incidence of penetration of the lateral wall of the pedicle because of medial inclination of the pedicle. The presence of a relatively high percentage of violation of the inferior pedicle wall could be because the starting point of screw insertion from the Roy-Camille technique may be too low; anatomic study has suggested that this point could be 3-8 mm above the line passing through the middle of the transverse process. Anatomic features of the thoracic pedicle and the results from the current study suggest that the screw insertion technique using fixed entrance point and orientation described by Roy-Camille are not reliable for pedicle screw insertion in all thoracic levels and would be associated with higher incidence of penetration of the thoracic pedicle.

The incidence and degree of pedicle wall violations were significantly reduced when screws were placed by using the open-lamina technique, it was noted that the incidence of pedicle wall violations was still high, with the main violations seen either on the medial or lateral walls of the pedicle. The high incidence of pedicle violation in the transverse plane may be because
the mediolateral diameter of the thoracic pedicle is significantly smaller than the superoinferior diameter and because of inaccurate determination of the screw entrance point and angle in the transverse plane, even though the superior and medial wall of the pedicle were directly located through a partial laminectomy.

Weinstein et al reported that the surgeon's experience did not play a significant role in improvement of the accuracy of pedicle screw placement after they compared the results of pedicle screw placement between an experienced surgeon and one less experienced. They also noted that a definite learning curve existed for both surgeons.

2.3 FUNNEL TECHNIQUE

Roy-Camille et al. suggested that a pedicle screw should be introduced by drilling the path and then applying the screw. Most American surgeons realized the danger of this approach; they adopted a blunt technique to identify the pedicle and routinely used biplane image intensification during the placement of pedicle screws. The use of taps of gradually increasing diameter to assess the quality of cortical purchase through the isthmus of the pedicle, and the use of image intensification to assess the length of the screw necessary to obtain purchase in the vertebral body but not through the anterior vertebral cortex, have become standard procedures for safe screw
application, resulting in strong fixation. This technique, called the Funnel Technique, is now used widely (Figure. 39).

Figure. 39 - Photographs illustrating the Funnel Technique. A: The dorsal
projection of the pedicle (circled) is localized. B: A one-centimeter-diameter section of cortical bone is removed over the top of the pedicle with a burr or Lexcel rongeur. C: The cancellous bone within the pedicle is then visualized. D: The cancellous bone is removed with a curet until the cortical wall of the pedicle can be felt and visualized. This is followed by going deeper into the pedicle toward the isthmus. E: The Kerrison rongeur is used to remove the cortical bone peripherally so that the isthmus of the pedicle can be seen. F: Once the isthmus of the pedicle is directly palpated, a small two-millimeter pedicle probe is passed through the isthmus into the vertebral body. G: A larger (five-millimeter) probe then is used to enlarge the path through the isthmus of the pedicle. H and I: Small Steinmann pin segments (fifty-five millimeters in length) are placed into the probed pedicles as radiographic markers. (The anteroposterior H: and lateral I: c-arm images confirm the pedicle path. The lateral can image [I] also confirm the length of the screw to be used; the depth of each Steinmann pin is measured after it is removed.) J: Threads then are cut into the pedicle with progressively larger taps until firm cortical purchase is achieved. The feel achieved during the tapping process determines the screw diameter that is used. K: A ball-tip probe is used to feel the pedicle in all directions: the bottom of the pedicle (in the vertebral body) and the superior, inferior, medial, and lateral inner walls of the pedicle. L: The screw then is inserted into the pedicle with the screwdriver. The purchase (insertional torque) must progressively increase until final seating. M: The anteroposterior and lateral c-arm images confirm proper positioning after all of the screws, rods, and connectors are inserted. (Grateful appreciation to
Byron R. Tarbox, M.D., Wicham Yingsakmongkol, M.D., Michael R. Viall, M.D., and EldinE. Karaikovic, M.D., Ph.D., for assistance with the "funnel technique.")

Irrigation with saline solution down the pedicle5, and visualization of the pedicle by an endoscope, have both been used to assess proper screw placement. Routine monitoring of somatosensory and dermatomal somatosensory evoked potentials, as well as electromyography, also have been used for this purpose. Unpublished data have suggested the need for routine laminectomy in patients with pedicle-screw fixation, although this approach has not been adopted widely. Hertlein et al. described the application of pedicle screws from the anterior approach. The use of robotics and computer-based guidance technology also has been investigated.

2.4 PEDICLE FIXATION IN SCOLIOSIS

Instrumentation that uses the pedicle as a source of purchase for bone screws from the posterior approach into the vertebral body has become an increasingly popular form of spinal fixation. Hamill et al compared correction of double major curves in 22 patients treated with hook configurations to 22 patients treated with pedicle fixation on the convex side of the lumbar spine. They found that pedicle screws on the convex side of the lumbar spine improved coronal and sagittal correction, allowed the lower instrumented vertebra to be translated to the midline and brought to a horizontal position, and allowed improved restoration of segmental lordosis. In a similar study, Barr
et al. found that the pedicle screws provided greater lumbar curve correction, better maintenance of correction, and greater correction of the uninstrumented spine below double major curves. Neither study reported any complications associated with the placement of pedicle screws.

An important concept in the use of pedicle screws is overcorrection of the lumbar curve if possible. Barr et al. found that because of the lateral placement of the pedicle screw, distraction on the concave side of the lumbar curve provided substantial correction of the tilt of the end vertebra in the coronal plane and helped produce a net overcorrection of the lumbar curve. In theory, overcorrection of the lower instrumented vertebra may reduce the number of levels in the fusion. However, Barr et al. noted no significant differences in the lowest vertebra fused in the hook and screw groups. They did suggest that the levels below the instrumentation were more normally oriented with screw instrumentation than hook instrumentation. Whether this improved correction and orientation of the lower levels below the fusion will decrease the incidence of low back symptoms or degenerative disc disease remains to be proved in long-term studies.

More controversial is the use of thoracic pedicle screws in the treatment of adolescent idiopathic scoliosis. Suk et al. compared correction with hook fixation to that with thoracic pedicle screw fixation. Correction was 55% with hooks and 72% with segmental thoracic pedicle screws. They reported a 3% malposition rate for the thoracic pedicle screws based on plain
roentgenograms. There were no malpositions, nor were there any neurological complications. Liljenqvist et al. used CT to evaluate 120 thoracic pedicle screws. Twenty-five percent of the screws penetrated the pedicle cortex or the anterior cortex of the vertebral body. There were no neurological complications. Curve correction was only slightly better with screws than with hooks. They noted that anterior penetration of the vertebral body cortex by a pedicle screw in the thoracic spine had the most clinical relevance because of the proximity of the thoracic aorta.

2.5 LUMBAR PEDICLE SCREWS

Zindrick described a "pedicle approach zone" (Figure 40)

Figure 40 - A, funnel-shaped pedicle approach zone in upper lumbar region (L1). B, Funnel-shaped pedicle approach zone in lower lumbar region (L5).
With increased pedicle size, pedicle approach zone funnel increases, especially in lower lumbar spine, allowing more latitude in pedicle screw insertion than in smaller upper lumbar and thoracic pedicles. (From Zindrick MR.: Spine: State of the Art Reviews 6:27, 1992.) that is decorticated before the pedicle is cannulated with either a drill or a probe. Most surgeons prefer to use a probe rather than any type of power instrumentation. Great care is taken to advance the instrument slowly and carefully. If resistance is encountered, the probe is repositioned. An intraoperative roentgenogram or C-arm image can be used to verify correct position. Instruments should pass relatively easily and should not be forced into the pedicle. In addition to roentgenograms or image intensification, laminotomy and medial pedicle wall exposure help confirm the intrapedicular passage of the instrument. Once satisfactory entry into the pedicle has been achieved and palpation from within the pedicle demonstrates solid bone margins along the pedicle wall throughout 360 degrees, the screw can be inserted. If the screws are self-tapping, the screw itself is inserted. If the screws require tapping, the tap is inserted first and then the screw. The common entry points in the lumbar spine are shown in Figure.41.
Figure 41 - Entrance points for pedicle screw placement in lumbar spine as described by Roy-Camille (X) and Weinstein (•). A. Lateral view. B. Posterior view. Weinstein approach reduces interference with upper uninvolved lumbar motion segment. (Redrawn from Weinstein JN, Spratt KF, Spengler D, et al: Spine 13:1012, 1988.)

The position of the pedicle in the sacrum is shown in Figure 42.

Figure 42 - Coronal posterior view of contribution of sacrum and posterior element to pedicle approach zone. (Redrawn from Zindrick MR: Spine: State of the Art Reviews 6:27, 1992.)

In the lumbar spine a medially directed screw allows the use of a longer screw and spares the facet joint, with less chance of injury to the common iliac vessels. Similarly a medially directed sacral screw reduces the possibility of injury to anterior structures if the screw penetrates the anterior cortex.

There is no uniformly accepted screw pattern for use in the lumbar spine in a double major curve. Chopin and Morin proposed that better three-dimensional correction can be achieved by using bilateral vertebral screws at the lumbar levels. Barr et al. recommended the use of one or two convex
apical screws with a concave pedicle screw on the inferior lumbar vertebra (Figure 43).

Hamill et al., on the other hand, found that pedicle screws on the convex side combined with one laminar hook on the distal instrumented vertebra on the concave side provided sufficient correction and allowed increased surface area for bone grafting on the concave side. Bait et al. recommended choosing the lowest instrumented lumbar vertebra on bending films. Instrumentation is stopped at the vertebra just above the first disc space that opens in the concavity of the lumbar curve on the bending film away from the concavity.

Derotation of the spine is better with screw fixation than with hook fixation because

The vertebral screws grasp the vertebral body and more laterally situated.
Hooks do not achieve as much rotation because they are too close to the spinous process and the spine does not follow the movement of the hooks (Figure 44)

Figure 44 - Use of bilateral vertebral screws at lumbar level, as recommended by Chopin for better derotation of spine. (From Chopin D. In Bridwell KH, Dewald RL, eds: The textbook of spinal surgery. Philadelphia, 1991, JB Lippincott.)

Hooks also may rotate in the lamina and lose some of the rotation correction. With screw fixation the first stage is still done on the convex side in the lumbar spine, with the same rotation of the contoured rod. No compression or distraction is applied at the first stage. The concave rod is then inserted and introduced into the intermediate screws. As the intermediate screws are approximated to the rod, more correction of rotation can be obtained with the rod introducer. Frontal alignment is then achieved with adequate compression on the convex side and distraction on the concave side at each level.
A study done by N. Rajagopalan et al in Indian cadavers the dimensions of lumbar pedicle were less when compared to results from western population.

<table>
<thead>
<tr>
<th>Level</th>
<th>ROYCAMILLE</th>
<th>KRUG</th>
<th>ZINDRICK</th>
<th>N RAJAGOP ALAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>8</td>
<td>7.01</td>
<td>8.7</td>
<td>7.3</td>
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<tr>
<td>L2</td>
<td>9</td>
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<td>8.9</td>
<td>7</td>
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<td>9.5</td>
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</tr>
<tr>
<td>LA</td>
<td>12</td>
<td>11.03</td>
<td>12.9</td>
<td>8.65</td>
</tr>
<tr>
<td>L5</td>
<td>15</td>
<td>15.15</td>
<td>18</td>
<td>10.6</td>
</tr>
</tbody>
</table>

Table No.3: Diameter of Pedicle in different studies.

2.6 THORACIC PEDICLE SCREWS: The diameter of the thoracic pedicles increases from cephalad to caudal.

Figure 45: Diameter of pedicle at different spinal levels
Suk et al. described placing pedicle screws at all levels in the thoracic spine. Even surgeons with a great deal of experience in the placement of thoracic screws have found a significant percentage to be malpositioned and therefore use fluoroscopy, which increases radiation exposure for both the patient and the surgeon. In addition, thoracic pedicle screws at every level add greatly to the expense of the instrumentation system. Whether the benefits of thoracic pedicle fixation in adolescent idiopathic scoliosis outweigh the potential risks and costs has not been proved at this time.

The thoracic pedicle is located at the base of the transverse process just medial to the lateral aspect of the pars intraarticularis. A high-speed burr is used to remove the outer cortical bone in this area, and fluoroscopy is used to confirm placement of a guide wire before final screw placement. Because of the smaller size of the thoracic pedicles, smaller diameter pedicle screws may be necessary.

**2.7 BIOMECHANICS OF PEDICLE SCREW FIXATION**

In 1986, Robert et al demonstrated the improved quality of spinal internal fixation provided by a pedicle-screw implant with a fixed link to a plate, in the first nonfailure stability testing done for spinal fractures. They also showed the fundamental importance of load transfer across the spinal column itself along with the implant - a concept known as load-sharing, which was subsequently widely adopted by the spinal surgery community. Biomechanical tests of
pedicle-screw constructs have demonstrated the fundamental importance of the bone-implant interface, bone density, and screw pullout strength. The essential need for fit and fill of the screw in the isthmus of the pedicle has been proved. The direct relationship between pullout strength and insertion torque has been well demonstrated, and the fundamental improvement in pullout strength obtained by cross-linking (that is, attachment of the two screws in an individual vertebra with use of a metal cross-link) has been documented. The stabilizing influence of using converging screws (a high pedicle angle [Figure. 46]), if possible, also was emphasized.

Figure. 46 - Drawings clearly illustrating the benefits of screw triangulation to improve pullout strength, particularly when the screws are cross-connected to one another. (Reprinted from: Barber, I. W.; Boden, S. D.; Ganey, T.; and Hutton, W. C.: Biomechanical study of lumbar pedicle screws: does convergence affect axial pullout strength? J. Spinal Disord., 11:216, 1998.)
The internal forces and moments of hi-level constructs have been measured exhaustively with strain gauges on all components of rod and plate-based constructs, and the fundamental importance of load-sharing through the vertebrae column has been reemphasized. Without load-sharing, an unstable four-bar mechanism\(^3\) was clearly demonstrated when all four pedicle screws were parallel (Figure. 47). In addition to in vitro testing, finite-element modeling has been used extensively to analyze stress transfer through implants as well as through implant-based constructs.

![Diagram of Axial and Lateral Forces](image)

**Figure 47** - The 4R-4bar linkage collapse associated with parallel pedicle screws (left) can be resisted only by load-sharing through the fracture site (right).
The bone-mineral density of vertebrae has been evaluated exhaustively with densitometry. Japanese investigators demonstrated conclusively that patients with multiple spontaneous compression fractures were very poor candidates for pedicle-screw-based internal fixation because their bone-mineral density was poor (one-fifth of normal bone density) preoperatively (Figure 48). Other authors have strongly suggested the routine use of bone-mineral-density testing before pedicle-screw-based surgery, although mild osteoporosis (bone-mineral density of less than 100 milligrams per milliliter) did not seem to affect screw purchase or clinical outcome adversely.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Normal trabecular pattern</td>
</tr>
<tr>
<td>0.5</td>
<td>Number of trabeculae normal; bone density decreased; trabeculae thin</td>
</tr>
<tr>
<td>1</td>
<td>Transverse trabeculae decreased; vertical trabeculae and end plate prominent</td>
</tr>
<tr>
<td>2</td>
<td>Transverse trabeculae more decreased; vertical trabeculae decreased</td>
</tr>
<tr>
<td>3</td>
<td>Transverse trabeculae almost disappeared; vertical trabeculae unclear, like a ground-glass image</td>
</tr>
</tbody>
</table>

Figure 48 - The "JIKEI Index" easily relates bone-mineral density and pedicle-screw pullout strength with his simple x-ray based scheme. Pullout strength is severely limited when there are spontaneous compression fracture as in
Stages 2 and 3. Pedicle-screw fixation is contraindicated when there is this much osseous deterioration. (Reprinted from: Soshi S.; Shiba, R; Kondo, H; and Murota, K An experimental study on transpedicular screw fixation in relation to osteoporosis of the lumbar spine, 16: 1336, 1991)

The success of hook-based constructs compared with that of screw-based constructs was shown to be based on bone-mineral density. In very osteoporosis specimens, hook-based claw constructs performed as well as screw-based constructs. A few authors have suggested use of both a screw and a hook at the same level. The enthusiasm for pedicle-screw fixation among spinal surgeons created a group of engineering collaborators who quickly became extremely knowledgeable regarding the engineering issues related to structural and clinical success. A model for fatigue testing that is now widely used was adopted by the American Society for Testing and Materials (Figure. 49). A corpectomy model is created with two polyethylene blocks to mimic vertebrae, which are attached to a standard 'Instron tester (Instron, Canton, Massachusetts). This model can be used for subcomponent or construct testing.
The major diameter of a pedicle screw has been shown to control pullout strength (Figure.50). Bicortical purchase both in individual vertebrae and in the sacrum increased pullout strength fundamentally, although bicortical purchase, except at the sacrum, has not been widely adopted by surgeons because of the risk of injury to the aorta or vena cava. Bicortical sacral purchase, however, has been proved to be extremely safe and has gained widespread acceptance. The first sacral segment has been analyzed exhaustively, and several safe and secure fixation sites have been demonstrated within it the anatomical liabilities of the second sacral segment also have been clearly shown.
Figure. 50 - Bar graphs showing the changes in pullout force (A) and bending stiffness (B) when screws with five and six-millimeter major diameters are compared. Improvements in both parameters are related directly to the major diameter of the screw. (Reprinted from: Wittenberg, R H; Lee, K-S.; Shea, M.; White, A. A, ill; and Hayes, W. C.: Effect of screw diameter, insertion technique, and bone cement augmentation of pedicular screw fixation strength. Clin. Orthop., 296: 282, 1993.)

The presence of one or more pedicle fractures has been shown to reduce, although not to completely eliminate, the integrity of pedicle-screw-based constructs. Many different styles of mechanisms have been developed by manufacturers to attach a pedicle screw to a longitudinal member (a plate or a rod); some are quite rigid and some, less rigid. All of these designs have shown some clinical utility, although there were dramatic differences in their biomechanical performance in vitro (Figure.51). The patient's body weight
has been shown to be the main determinant affecting structural survival of rods used for scoliosis correction.

Figure 51 - Bar graphs showing differences in resistance to cyclic loading. All of these implant systems have been used extensively, although their biomechanical performance differs dramatically. The healing of the fusion is much better in patients with stiffer implants. VSP = variable screw placement (steffee) plate, KPL = Kirschner plate, DLO = Dyna-lok plate, ISO = Isola rod, CCD = Compact CD (Cotrel-Doubousset) rod, CDC = CD cold rolled rod, FIX = AO fixateur interne, CDS = CD standard rod, and KRO = Kirschner rod (Reprinted: Cunningham, B.W.; Sefter, J.C.; Shono, V and McAfee, P. C. Static and cyclical biomechanical analysis of pedicle screw spinal constructs. Spine, 18: 1681, 1993.) Nitrite has been added to the surface of the screw to improve surface hardness, and both titanium and steel implants have been widely investigated, manufactured, and used. Titanium implants are used for patients who are allergic to nickel, chromium, or cadmium or for those who
may require frequent postoperative magnetic resonance imaging or computed tomographic scans.

2.8 SUPPLEMENTAL TECHNIQUES OF PEDICLE-SCREW FIXATION

Methylmethacrylate has been used in vitro and in vivo to improve the fixation of pedicle screws in vertebrae (Figure 52). The improvement in pullout strength is obvious. However, the occasional spread of the cement into the spinal canal limits the successful application of this technique. The use of calcium phosphate\(^1\)\(^2\)\(^2\) has been reported, but there has been very limited acceptance of this option. The use of carbonated apatite also has been reported.

Figure 52 Graph showing improved screw-bending stiffness due to the addition of polymethylmethacrylate (PMMA) and polypropylene glycolfumarate (PPF) (Reprinted, with permission, from: Wittenberg, R.H.; Lee, K-S Shea, White A.A. III; and Hayes, W. C.: Effect of screw diameter, insertion technique, and bone cement augmentation of pedicular screw fixation strength. Clin. Orthop., 287: 284, 1993.)
Early clinical reports of pedicle-screw fixation demonstrated that most pedicle screws did not obtain cortical purchase (only cancellous purchase was obtained), whereas recent reports have emphasized the essential nature of cortical purchase and the direct relationship between pullout strength, insertional torque, and bone-mineral density. In our practice, the use of the direct Funnel Technique to identify the pedicle isthmus permits tapping the isthmus to obtain cortical purchase for each inserted screw. Bicortical purchase is routinely used at the first sacral level but never at any other level. The improvements in fixation at individual vertebral levels stimulated the need for improvements in spinopelvic fixation to manage spinopelvic disorders with greater security. Iliosacral screws, iliac-wing screws, intrasacral fixation, and lumbosacral endplate fixation all have been recommended, researched, and adopted in limited applications for specific indications.

2.9 USE OF BONE-GRAFTING MATERIALS

With improved spinal internal fixation, surgeons have attempted to limit their use of extra autogenous bone graft to avoid morbidity at the donor site. Bone stimulators, allograft materials, synthetic hydroxyapatite, calcium phosphate, and coral all have been used with pedicle-screw-based constructs, with greater or lesser success depending on the pathology and the host-related variables. Smoking has been demonstrated to be a risk factor for pseudarthrosis in some series but not others.
2.10 ALTERATIONS IN SPINAL FUSION TECHNIQUES DUE TO IMPROVED SKELETAL FIXATION PROVIDED BY PEDIC1E-SCREW-BASED IMPLANTS

Many surgeons have abandoned formerly routine techniques of spinal fusion such as decortication of the posterior elements or facet fusion when pedicle-screw-based implants are used. The time to healing of a scoliosis fusion was reduced from 6 to 12 months in the 1690s to two to four months in the 1990s because of the secure internal fixation provided by pedicle screw based implants. There has been a decrease in the need for postoperative bracing of patients with constructs based on internal fixation with pedicle screws. This has been particularly notable in patients with scoliosis.

2.11 PEDIC1E-SCREW-BASED IMPLANTS

Stress-shielding of bypassed vertebrae under implants that were deliberately, disproportionately large has been well documented in dogs. However, loosening of these huge implants from the host spine occurred when the bypassed spinal segment was osteoporotic. After screw-loosening, the stress-shielding effect of the disproportionately large implants was alleviated and the bone density of the bypassed segment of the spinal column returned to normal.

2.12 IMAGING OF PEDIC1E-SCREW-BASED CONSTRUCTS.

The limitations of plain radiographs and computed tomography in demonstrating proper screw position have been well documented. Surgical
exploration is the reference standard for determining union. Only the radiographic demonstration of trabeculation across the intertransverse (lateral) or interbody area comes close to surgical exploration with regard to accuracy in determining the presence or absence of solid union of a spinal fusion.

2.13 ADJACENT SEGMENTS

Static kinematic testing has been used to examine and identify the increased motion that occurs at motion segments adjacent to spinal constructs immobilized by pedicle-screw-based implants. Finite-element models also have demonstrated this increased motion. Case reports of spinal fractures occurring adjacent to spinal instrumentation constructs have documented clinically the vulnerability of the spine after a violent injury. Disc pressures are substantially changed adjacent to a spinal instrumentation construct as well. Other case reports have demonstrated the necessity of protecting the supraspinous and interspinous ligaments, the ligamentum flavum and the capsular ligaments at segments adjacent to a spinal instrumentation construct, and they have shown the importance of restoring balance in the sagittal plane to avoid degeneration of adjacent segments.

2.14 INDICATION FOR PEDICLE-SCREW-BASED FIXATION

Although the initial clinical use of pedicle-screw-based implants was based on their theoretical benefits, their effectiveness in facilitating fusion now has
been demonstrated conclusively. Collaborative and individual studies have demonstrated statistically higher fusion rates associated with use of these implants. The functional benefits for patients also have been demonstrated conclusively with use of preoperative and postoperative testing.

Pedicle screws have dramatically improved the outcomes of spinal reconstruction requiring spinal fusion. Short-segment surgical treatments based on the use of pedicle screws for the treatment of neoplastic, developmental, congenital, traumatic, and degenerative conditions have been proved to be practical, safe, and effective. The Funnel Technique provides a straightforward, direct, and inexpensive way to very safely apply pedicle screws in the cervical, thoracic, or lumbar spine. Carefully applied pedicle-screw fixation does not produce severe or frequent complications. Pedicle screw fixation can be effectively and safely used wherever a vertebral pedicle can accommodate a pedicle screw — that is, in the cervical, thoracic, or lumbar spine. Training in pedicle-screw application should be standard in orthopaedic training programs since pedicle-screw fixation represents the so-called gold standard of spinal internal fixation. Pedicle screws have revolutionized the surgical treatment of spinal disorders, although their introduction and widespread adoption by spinal surgeons has created one of the most difficult regulatory problems ever seen in orthopaedics.
Mainly on the basis of the results of treatment of scoliosis and the desire to ensure load-sharing in the anterior column, many low-back surgeons in the United States routinely began to use circumferential fusion for all cases of degenerative spinal disease after anterior and middle-column load-sharing was demonstrated to be beneficial biomechanically. Anterior grafting was performed either with an anterior open procedure, a laparoscopically based anterior procedure, or posterior lumbar interbody fusion at the same time as the pedicle-screw-based surgery. Some authors have suggested that the routine use of circumferential fusion improves the healing rate in smokers and that the union rate is better than that obtained with pedicle-screw-based intertransverse fusion alone. The development of prosthetic devices that contain autograft or allograft has added another variable to this clinical interface that is still under investigation. An unpublished review of the results in our patients demonstrated a 92 percent union rate with pedicle screw-based posterolateral fusion alone, without cages, using only the autograft obtained from laminectomy for the majority of patients. None of the patients had anterior surgery. The union rate in smokers and nonsmokers was the same.

2.16 COMPLICATIONS

Complications have accompanied the use of pedicle screws. The rate of
screw misplacement has ranged from 20 to 25 percent in patients with scoliosis and to nearly 4.2 percent in those with degenerative diseases. A learning curve has been demonstrated for surgeons in general. A variable prevalence of nerve-root and/or cauda equina injury has been reported to be associated with pain and sensory deficit in some patients. The prevalence has been reported to be as high as 11 percent and as low as 1 percent to 2 percent. However, most misplaced screws do not create nerve-root injury. Safe removal of screws that were drilled into the spinal canal has been reported. A high prevalence of screw misplacement associated with drilling rather than with the blunt technique of screw application has been clearly demonstrated. Computer-based navigation techniques have been developed and have been suggested for clinical application. Some authors have suggested that the routine use of computer navigation improves screw placement. A dural injury was reported in seven of 124 patients and in two of eighty nine patients in two series of pedicle-screw fixation for the treatment of degenerative spine disease. Deep-infection rates have ranged from 1.1 percent (five of 470 patients) to 4.2 percent. Prompt wound debridement and administration of antibiotics, with preservation of the implant and subsequent delayed primary closure, have been adopted routinely, with acceptable intermediate-term clinical outcomes. The use of pedicle-screw-supplemented fusion has been reported to enhance the results of primary operative treatment of hematogenous discitis and osteomyelitis. The frequency of
screw breakage has ranged from 2.6 percent to 4.9 percent to 9 percent to 36 percent to as high as 60 percent. However, survivorship analysis of a series of patients who had degenerative disease indicated that the clinical survival of pedicle-screw-based constructs was similar to that of total hip and total knee reconstructions. The two alarmingly high screw-breakage rates were reported when highly comminuted spinal fractures were internally fixed with posterior short-segment pedicle-screw-based instruments. The load-sharing classification provides a simple way to differentiate fractures according to comminution. It suggests that anterior vertebrectomy, strut-grafting, and instrumentation be performed in patients with severely comminuted injury to avoid the high screw-breakage rates that occur when short segment posterior pedicle-screw-based instrumentation is used for highly comminuted injuries (Figure. 53).

Figure. 53 - The load-sharing classification permits quantification of comminution of spinal fracture sites so that the load-sharing capability of the injured vertebral body itself, along with the implant system, can be determined. This approach has allowed surgeons to perform short-segment fixation for most isolated spinal fractures in cooperative patients. A:
Comminution/involvement. 1 = little comminution (less than 30 percent), 2 = more comminution (30 to 60 percent), and 3 = gross comminution (more than 60 percent) on computed tomographic sagittal plane sections. B: Apposition of fragments. 1 = minimal displacement, 2 = spread of displacement (at least two millimeters of displacement of less than 50 percent of the cross section of the body), and 3 = wide displacement (at least two millimeters of displacement of more than 50 percent of the cross section of the body). C: Deformity correction. 1 = kyphotic correction of 3 degrees or less, 2 = kyphotic correction of 4 to 9 degrees, and 3 = kyphotic correction of 10 degrees or more on lateral plain radiographs. Reprinted from: McColllack, I.; Karaikovic, E.; and Gaines, R. W.: The load sharing classification of spine fractures. Spine, 19: 1742, 1994.)

Screw pullout and screw-connector disengagement have been reported both in vitro testing and in patients. Rod breakage has been reported only rarely. Most authors have described problems with the screw or the bone-screw interface but not with the longitudinal component. Screw-thread fracture has never been reported. There are established methods for removing broken screws.
2.17 UNION RATE IN WITH PEDICLE-SCREW-BASED CONSTRUCTS

The union rate associated with pedicle-screw-based constructs generally has been reported to be nearly 90 percent. The benefits provided by very stiff implants were demonstrated statistically in a prospective, randomized trial comparing the rate of union associated with these implants with the rates obtained without use of an implant and with use of a semirigid implant.

2.18 LATE RESULTS IN PRESENCE OF IMPLANTS

Implant-related pain has led to the need to remove the implant from some patients. The clinical benefits of implant removal have not been uniformly demonstrated.
References


