Transpedicular screw-rod fixation of the lumbar spine: operative technique and outcome in 104 cases

CURTIS A. DICKMAN, M.D., RICHARD G. FESSLER, M.D., PH.D., MICHAEL MACMILLAN, M.D., AND REGIS W. HAD, M.D.

Departments of Neurosurgery and Orthopaedic Surgery, University of Florida College of Medicine, Gainesville, Florida

A total of 104 patients underwent transpedicular spinal instrumentation using the Cotrel-Dubousset (71 cases) or the Texas Scottish Rite Hospital (33) screw-rod system. Surgery was performed for lumbar vertebral column instability secondary to fractures (28 cases), spondylolisthesis (29), tumors (four), vertebral osteomyelitis (two), or postoperative causes (41). Pseudoarthrosis due to failure of a prior fusion was present in 37 cases.

The 55 men and 49 women (mean age 47 years, range 18 to 87 years) all presented with severe back pain. Signs or symptoms of neural compression were noted in 96 patients. Surgery consisted of neural decompression, internal fixation, and autogenous iliac bone grafting. Spondylolyses were fused in situ, without reduction; otherwise, major spinal deformities were corrected. A total of 516 pedicle screws were placed. The mean extent of fusion was 2.7 motion segments (range one to six motion segments).

A 96% fusion rate was obtained with a mean follow-up period of 20 months. There were no operative deaths. Major complications included one spinal epidural hematoma, three isolated nerve root deficits (two transient, one permanent), and three wound infections (two deep, one superficial). Instrument failure eventually developed in 18 patients; nine were asymptomatic with a solid fusion and did not require further treatment and the other nine were symptomatic or had a pseudoarthrosis and required operative revision.

Pedicle screw-rod fixation offers biomechanical advantages compared to other forms of internal fixation for the lumbar spine. It enables short-segment fixation with preservation of lumbar lordosis and adjacent normal motion segments. This technique provides a highly successful method to obtain arthrodesis, even with prior pseudoarthrosis.

KEY WORDS • screw fixation • pedicle • spinal fusion • spinal instrumentation

DURING the last 30 years, the development of instrumentation for internal spinal fixation has evolved rapidly. Fusion rates have improved with the use of internal fixation compared to onlay fusion techniques. Technical advances and refinements in instrumentation have provided a variety of surgical options. Transpedicular screw fixation has become an important method for internal fixation in a variety of disorders and is particularly well suited for lumbar spinal fusion. This technique provides a strong segmental vertebral fixation and is associated with high rates of osseous union. Compared to posterior wire-rod or hook-rod systems, transpedicular screw systems allow internal fixation of significantly fewer motion segments and provide better segmental fixation. Three-column spinal stabilization, preservation of normal adjacent motion segments, and prevention of mechanical pain syndromes are possible. Successful application of transpedicular screw systems requires a thorough knowledge of pedicular anatomy, regional vertebral morphology, and the biomechanical principles of this instrumentation.

This study analyzed the long-term results in a large group of patients treated with lumbar pedicle screw-rod fixation. The surgical anatomy, operative techniques, biomechanical principles, and the merits and pitfalls of this method are described.

Clinical Material and Methods

Patient Population

A total of 104 consecutive cases of lumbar spine instability were treated by the authors at the University of Florida between 1987 and 1991 using exclusively transpedicular screws for vertebral or sacral attachment. The hardware was from the Cotrel-Dubousset (CD) or Texas Scottish Rite Hospital (TSRH) universal instru-
Transpedicular screw-rod spinal fixation

The patient population consisted of 55 men and 49 women, with a mean age of 47 years (range 18 to 87 years). All patients had clinical and radiographic evidence of lumbar spinal instability. All patients suffered severe back pain; however, surgery was never performed solely to treat isolated back pain. Ninety-six patients presented with neurological signs and symptoms due to spinal cord or conus medullaris compression (23 cases) or compression of single or multiple nerve roots (73). The other eight patients presented with severe back pain without neurological symptoms from failed therapeutic fusions.

Forty-three patients had had no prior surgery, and 61 patients had undergone previous surgery on the lumbar spine for neural decompression or internal fixation (mean 1.4 operations/patient, range one to five operations/patient). Symptomatic pseudoarthrosis due to failure of a prior fusion was noted in 37 patients at examination, with 26 of these cases occurring after onlay or posterior interbody fusion techniques without instrumentation and 11 occurring despite posterior instrumentation for internal fixation.

The pathological conditions responsible for lumbar spine instability were fractures in 28 patients, isthmic or degenerative spondylolisthesis in 29, primary or metastatic neoplasms in four, vertebral osteomyelitis in two, and postoperative instability after operations for spinal stenosis in 26, for herniated discs in nine, for scoliosis in five, or for intradural tumor in one. Patients with fractures, infection, or tumor usually presented with acute or subacute symptomatic pathology characterized by sudden onset of back pain, neurological deficits, and spinal deformities. Patients with acute pathology who had a greater than 50% loss of vertebral body height, more than 30° of vertebral angulation, or a vertebral subluxation over 10 mm were considered for surgery without a trial of nonsurgical therapy. Patients with acute neurological deficits were managed with operative intervention as soon as they were clinically stable, usually within 7 days of presentation.

Seventy patients presented with chronic symptoms from lumbar spinal instability. Progressive neurological deficits due to compression were the primary surgical indications in this group. Nonsurgical therapy, such as external bracing, physical therapy, exercises, analgesics, and facet blocks, was usually initiated to attempt to resolve the patients' symptoms. Patients with spinal deformity or radiographic evidence of abnormal motion who demonstrated relief of back pain or radicular symptoms after external bracing and who experienced a return of symptoms after brace removal were candidates for fusion.

Clinical and Follow-Up Studies

The patients' medical records and radiographic studies were analyzed individually. Clinical data were recorded with respect to the type of pathology, extent and etiology of instability, contributing medical history, symptoms, details of instrumentation and fusion, operative complications, correction of spinal deformity, and long-term outcome with regard to the status of instrumentation, fusion, and symptoms. Follow-up evaluation consisted of re-examination of the patients, review of outpatient physician records, telephone interviews, and postoperative radiographic analysis. Long-term follow-up study was achieved in 96 of the 104 patients, with a mean postoperative duration of 20 months (range 10 to 49 months). Of the eight patients followed for less than 6 months, six patients were lost to follow-up evaluation and two patients died from metastatic tumors.

Radiographic Studies

Complete pre- and postoperative radiographic evaluations were performed. Plain radiographic studies of the lumbar spine included anteroposterior, oblique, and lateral views, and whenever possible, supine/standing and flexion/extension comparisons. Myelography, computerized tomography (CT), or magnetic resonance imaging was obtained to assess unstable segments, to define the extent of neural compression, and to evaluate adjacent vertebral levels.

Preoperative, postoperative, and long-term radiographic parameters were compared. The kyphotic angle was assessed by measuring the vertebrae above and below the pathological levels according to the posterior vertebral body method.4,20 In cases of subluxation, the extent of displacement, the wedge index (anterior vertebral height + posterior vertebral height), and the extent of vertebral collapse were measured.

Fusion was established radiographically by visualizing continuous posterolateral bone fusion via anteroposterior, lateral, and oblique views. When routine radiography was indeterminate, anteroposterior and lateral tomography was employed. Pseudoarthrosis was defined clinically and radiographically as a discontinuity or fibrous interface between fusion segments or as motion at a fused level. Independent radiographic analysis by a staff radiologist was performed in addition to that by the authors.

Surgical Procedures

All patients underwent a pedicle screw instrumentation and fusion procedure. Those with evidence of neural compression were treated with decompressive surgery. Posterior midline or posterolateral approaches for decompression were employed in 90 cases. A lateral retroperitoneal approach for decompressive vertebrectomy and interbody reconstruction was performed in six cases. Allograft bone struts were utilized in five patients (Fig. 1) and methyl methacrylate packing in one for reconstruction. A total of 71 CD and 33 TSRH screw-rod systems were placed for internal fixation. Bilateral fixation was achieved solely with pedicle screw-rod systems, with the rods transversely crosslinked in all cases. A total of 516 pedicle screws were placed.
(mean 4.9 screws/patient, range four to 10 screws/patient).

The mean extent of fusion was 2.7 motion segments (range one to six motion segments); 76 patients had either two or three motion segments instrumented and fused (Fig. 2). Pedicle screws were placed only within the lumbar vertebrae in 55 patients, while in 49 patients the instrumentation and fusion extended from the lumbar spine to the sacrum or lower thoracic spine. Grafts of autologous iliac bone (96 cases), a mixture of autograft and allograft bone (three), or allograft bone (three) were placed for posterolateral fusion. No posterior bone graft was placed in the two patients with active vertebral osteomyelitis.

Operative Technique

Positioning and Exposure

General endotracheal anesthesia was administered with the patient on a cart or bed, and pneumatic compression stockings were applied to the legs. The patient was connected to a blood product recycling unit,* unless contraindicated. Prophylactic administration of intravenous antibiotics (vancomycin and gentamicin) was initiated preoperatively and continued for 48 hours postoperatively. Whenever possible, autologous blood was donated in advance.

Radiolucent operating tables with an adjustable fluoroscopic "C-arm" image intensifier and patient frames or chest rolls were used to permit intraoperative anteroposterior, oblique, and lateral fluoroscopy of the spine. The patients were placed in the prone position on the operating table, with the thorax supported laterally to avoid epidural venous distention from abdominal compression. A midline lumbar incision was made, extending 2 to 3 in. above and below the segments to be instrumented in order to allow adequate tissue retraction and to avoid tension on the wound. Subperiosteal muscular dissection of the segments to be fused was performed with a wide exposure to the lateral tips of the transverse processes. Neural decompression and vertebral body reconstruction were performed as indicated prior to posterior instrumentation.

Pedicle Preparation and Screw Placement

After the spine was exposed and decompressed, the external landmarks over the pedicles were localized. Pedicle identification, hole preparation, and screw placement were performed under fluoroscopic observation.

In the lumbar spine, the external landmarks for the pedicles were at the intersection of the axial plane through the middle of the transverse processes and the sagittal plane through the superior facet (Fig. 3). Identification of the facet complex was facilitated by moving the spinous process with a Kocher clamp and then removing the soft tissue from the surface of the superior facet.

A Steinmann pin was placed over the external landmark, and the correct entry position was verified radiographically. The pin was oriented along the axis of the central portion of the pedicle. On anteroposterior or slightly oblique fluoroscopic images, the pedicle and aligned pin appeared as an oval structure containing a central dot, creating a "bull's eye" or "target sign" (Fig. 4). The C-arm was rotated aside and the cortical bone at this posterior site was penetrated with a high-speed drill.

Sacral screw sites were prepared in a manner similar to the lumbar pedicle screw sites. The external anatomical landmarks differed from those in the lumbar region since the sacrum had no transverse processes (Fig. 5). Manipulating the L-5 spinous process helped to identify the L5-S1 facets. Soft tissue was cleared from the sacrum to delineate the first dorsal sacral foramina and the osseous recession caudal to the L5-S1 facets. The external landmark for the first sacral pedicle was located at the inferolateral portion of the superior S-1 facet. The correct entry sites into the S-1 pedicles were fluoroscopically verified.

Hole preparation for the screw was performed by penetrating through the posterior cortex, deepening the hole past the narrow midportion of the pedicle, and completing the hole to the desired depth. Preparation of the hole and insertion of the screw required proper orientation relative to the central axis of the pedicle.

Under anteroposterior fluoroscopic monitoring, a hole was made in the pedicle via a Steinmann pin with a diameter corresponding to the minor diameter of the screw (for example, a ½-in. pin for a 5.5-mm screw or a 5/16-in. pin for a 6.5-mm screw). The pin was affixed to a Jacob's chuck on a T handle and manually driven through the center of the pedicle with a firm twisting motion (Fig. 6). This procedure was repeated at each

* Cell saver blood product recycling unit manufactured by Haemonetics Corp., Braintree, Massachusetts.
Transpedicular screw-rod spinal fixation

Fig. 2. Examples of spinal reconstruction, with radiographs showing a single motion-segment fusion at L4-5 (left and center) and an L4-S1 fusion (right).

Fig. 3. Drawing showing the landmarks for identification of the pedicles in the thoracic and lumbar spine at the intersection of the axial plane through the transverse processes and the sagittal plane through the superior facet.

Fig. 4. Radiograph showing a Steinmann pin aligned with the central axis of the pedicle. The "bull's eye" appearance indicates the correct entry point and trajectory through the center of the pedicle.

Fig. 5. Drawing depicting the external landmarks for identification of the first sacral pedicles. The entry point was on the superior S-1 facet, lateral to the facet recess at L5-S1, and cephalad to the S-1 dorsal foramen.

Fig. 6. Photograph of the tools used in pedicle screw-rod fixation. Left: A T-handled Jacob's chuck, Steinmann pins, and a T-handled bone awl were used to prepare the screw holes. Right: Screwdrivers and a hook holder were needed for pedicle screw manipulation.
pedicle, and the final anteroposterior orientation of each pin was assessed fluoroscopically.

The progress of pin and screw penetration into the vertebral body was monitored using lateral imaging. Each pin was manually driven deeper and positioned to the endplate of the vertebrae; however, penetration into the adjacent disc space was avoided. This maneuver required a vertical orientation for the lumbar spine and a 30° caudal angle for the sacrum (Fig. 7). The medial trajectory corresponded to the angle of the pedicles at each level. Penetration of the pin through the hard pedicle into the soft cancellous bone of the vertebral body provided a distinct feel, with a reduction in resistance.

After all pins were placed into the vertebral bodies to create tracks for the screws, the Steinmann pins were removed, and the superficial 5- to 10-mm area of each track was enlarged with a drill or bone awl. This allowed the threads of the pedicle screw to engage a purchase upon the bone.

Pedicle screw sizes were preselected on the basis of the CT characteristics of the particular vertebra. The screws were placed into the prepared holes with an identical trajectory to that of the Steinmann pins. Screw purchase was obtained by advancing the screw with a screwdriver, penetrating 70% to 80% of the vertebral body. The anterior portion of the vertebral body was not penetrated in order to avoid injuring the vascular and visceral structures anterior to the vertebral column. Throughout the procedure, the progress, depth, and position of the screws were monitored.

Rod System Assembly

A malleable wire or sterile endotracheal tube stylet was used as a template to approximate the desired rod curvature. The rods were selected, cut to the desired length, and bent to match the contour of the template. An S-shaped curve was used for thoracolumbar rods and a lordotic curve for lumbar or lumbosacral rods. The rods were connected bilaterally to the pedicle screws by either threading the rods through the screws (CD system) or attaching the eyebolts to the rods (TSRH system) and then tightening the nut assemblies (Fig. 8).

Final adjustments in rod contour were achieved with in situ rod benders. Hook holders, corkscrew devices, wrenches, and a variety of other tools helped to connect the rods and screws (Fig. 9). Spinal reductions were performed and instruments were placed under compression, with distraction, or in a neutral position as indicated. A transverse traction device (CD system) or crosslinks (TSRH system) connected the right and left rods. All connections of the screws, rods, and transverse stabilizing components were securely tightened for final fixation.

Fusion Site Preparation and Wound Closure

The vertebrae beneath the full length of the instrument system were fused. The fusion site was usually prepared prior to rod placement, thereby providing more working space for bone preparation. After all soft tissue was removed from the surface of the fusion bed, a high-speed drill was used to decorticate the transverse processes, facet joints, and other bone fusion surfaces. The articular surfaces of the facet joints were curetted or drilled to remove the cartilage, and cancellous bone grafts were packed into the facets. After rod placement and thorough wound irrigation with bacitracin solution, cancellous bone and cortical matchstick grafts were placed for a posteroslateral fusion. Autogenous iliac bone was the preferred grafting material. Closed suction-
Transpedicular screw-rod spinal fixation

![Fig. 9. Photographs showing tools used in screw-rod fixation procedures. Left: Rod-bending tools included (left to right): French benders, \textit{in situ} benders, and hollow bending irons. Center: Screw-rod assembly tools included (left to right): a corkscrew device, a hook holder, and an eyebolt compressor. Right: Instrumentation manipulation tools included (left to right): a rod rotator, a rod pusher, a distractor, and a compressor.]

Drainage systems were placed and a routine multilayered wound closure was performed.

Postoperatively, patients with lumbar fusion wore a thoracolumbar sacral orthosis device for 3 to 6 months. Patients with lumbosacral fusion wore an orthosis device with one thigh immobilized. Patients were ambulatory or mobilized within the first few postoperative days. Progressive rehabilitative therapy was administered.

**Results**

**Neurological Function and Back Pain**

Neurological improvement occurred in 85 of the 96 patients presenting with deficits. In the 73 patients with nerve root or cauda equina compression, 66 patients had improved motor function or resolution of radicular pain; 49 of these patients recovered normal function. Improved motor function or sensation (average recovery 1.6 Frankel grades) was experienced by 19 of the 23 patients with spinal cord or conus medullaris compression; five of these patients recovered normal function.

The resolution of back pain was more variable than neurological recovery. The criteria for evaluation was based on the patients' subjective responses regarding limitations due to their back symptoms (Table 1). Severe, incapacitating back pain was present preoperatively in the entire patient population. Postoperatively, 20 patients had excellent relief of back pain, 57 had moderate back pain, and 19 had severe, persistent pain.

**Fusion Rate**

At long-term follow-up examination, 92 (96%) of the 96 patients developed osseous unions. These patients demonstrated continuous radiographic fusion masses on plain radiographic studies or tomography and no clinical or radiographic evidence of instability.

**TABLE 1**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>complete resolution of back pain or minor intermittent back pain</td>
<td>20</td>
</tr>
<tr>
<td>moderate intermittent back pain, able to function independently, work, or conduct normal activity</td>
<td>57</td>
</tr>
<tr>
<td>incapacitating or severe back pain, unimproved from preoperative pain; unable to work or function independently</td>
<td>19</td>
</tr>
</tbody>
</table>

Pseudoarthrosis occurred in four patients, three of whom underwent additional surgery for reinstrumentation and fusion with successful results. The fourth patient refused another operation, which would have been her fifth lumbar procedure, and continues to have severe back pain. Factors contributing to nonunion included fresh frozen allograft bone in two patients, prior pseudoarthrosis in three, osteoporosis in two, obesity in two, and cigarette smoking in two. Although patients with a prior pseudoarthrosis had a higher risk of failure, the fusion rate for this group of patients was excellent after pedicle screw instrumentation; 34 (92%) of the 37 patients developed osseous unions.

**Correction of Deformity**

In the patients with spondylolisthesis, the vertebrae were fused \textit{in situ} without attempting to correct the spinal deformity since reduction in these cases has been associated with increased instrument failure and neurological complications. Reduction of the spinal deformity was attempted to some degree in all other patients (mean reduction 14°). Nineteen patients
underwent major reductions, which were defined as a correction of 1 cm or more of vertebral body height or a reduction of 30° or more of sagittal angulation. Ten patients developed a minor reversal of correction during a long-term follow-up period, with a mean loss of reduction of 2.4°.

**Complications**

Three of the four patients who suffered neurological complications developed new postoperative radiculopathy. In one patient, the radiculopathy resolved spontaneously, with no radiographic evidence of root impingement, and was attributed to intraoperative root manipulation during foraminotomy. Two cases of radicular deficits occurred secondary to pedicle screw malpositioning and were treated with removal of the offending screw and foraminal decompression. One patient completely recovered; the other had persistent unilateral L-5 weakness and numbness at 21 months postsurgery.

The fourth patient with neurological complications developed a cauda equina spinal epidural hematoma due to a postoperative coagulopathy. Although this complication was treated with urgent operative decompression, the patient had residual neurological dysfunction.

Three wound infections (one superficial and two deep) developed postoperatively. The superficial infection cleared with local wound debridement, packing, and oral antibiotic therapy. The two deep wound infections cleared after open debridement, irrigation, primary closure, and parenteral antibiotic treatment. The instrumentation was not removed in these cases and no recurrent infections developed. Subsequently, all three patients attained a successful arthrodesis.

Other perioperative complications included pneumonia in six patients, urinary tract infection in nine, deep venous thrombosis in three, and a decubitus ulcer in one. Four intraoperative dural tears occurred unrelated to instrument placement; these tears were satisfactorily treated with primary closure of the dural defect. There were no postoperative deaths.

**Instrument Failure**

Instrument failure eventually developed in 18 cases. Nine patients were asymptomatic with solid fusions, and required no therapy. In the other nine patients, the instrument failure was symptomatic or associated with a pseudoarthrosis and required operative revision.

Trauma was responsible for two early cases of instrument failure. Both patients fell and dislodged the screw-rod systems within the first 8 weeks postsurgery. These patients required immediate operative revision. The rods became uncoupled from the screw systems in six patients. Four of these required operative revision, two for instrument prominence and two for pseudoarthrosis. No rods bent or broke. The screws failed in 10 patients (Fig. 10), three of whom required reoperation. There were nine bent screws, six broken screws, and 10 loose screws, representing a 4.8% screw failure rate (25 of 516 screws). Five of the six screws that broke had a narrow diameter (4.5 or 5.0 mm); the other was 7 mm in diameter. Screw breakage was eliminated after the use of narrow-diameter screws was discontinued. A variety of screw sizes (5 to 7 mm) bent or loosened. There were no significant differences in the instrument failure rate between the CD and the TSRH systems.

**Discussion**

**Operative Indications**

The most important issues regarding these procedures are the appropriate indications for lumbar fusion and how to select patients for surgery. Since internal fixation and fusion are major operative procedures with significant risks, they should be reserved for patients with major spinal deformities, instability associated with neurological deficits, or a high risk of progressive spinal deformity. Fusion is needed if pathological spine motion is associated with neural compression or if the spine is destabilized during neural decompressive procedures.

Spinal fusion is not effective for the treatment of isolated chronic back pain. We do not advocate surgery to treat severe back pain in the absence of neurological deficits or obvious instability. Our experience confirms that a large proportion of patients continue to have moderate or incapacitating back pain despite a satisfactory fusion and neurological recovery. Chronic postoperative back pain may represent an undetected pseudoarthrosis; therefore, these patients must be evaluated thoroughly and followed meticulously.

Instrumentation improves the probability of achieving a spinal fusion. Fusions with instrumentation are more rigid than fusions without instrumentation. As the rigidity of the spinal instrumentation increases, so does the probability of a successful fusion.
Transpedicular screw-rod spinal fixation

Screw-rod systems are invaluable for patients who have a pseudoarthrosis or for those at high risk for nonunion, such as obese patients and smokers.

**Advantages of Pedicle Screw Instrumentation**

Pedicle screw-rod systems have several advantages compared to other instrumentation systems for internal fixation of the lumbar spine. They provide rigid segmental fixation along all three columns of the spine and allow a combination of forces (distraction, compression, or rotation) to be selectively applied to spinal segments.\(^1\)\(^2\)\(^3\)\(^4\)\(^5\)\(^6\)\(^7\)\(^8\)\(^9\) The screw-pedicle interface is a biomechanically superior fixation site compared to the hook-lamina or wire-lamina interface.\(^1\)\(^2\)\(^9\)\(^6\)\(^7\)\(^8\)\(^9\) Segmental vertebral fixation improves the ability to correct a spinal deformity.\(^1\)\(^2\)\(^9\)\(^6\)\(^7\)\(^8\)\(^9\)

Compared to other posterior instrumentation systems, fewer levels of the spine are instrumented and fused with pedicle screw-rod systems.\(^1\)\(^2\)\(^9\)\(^6\)\(^7\)\(^8\) In hook-rod systems, five to seven segments usually need to be fixed;\(^3\)\(^8\)\(^9\)\(^15\)\(^26\) in contrast, pedicle screws can provide fixation of a single motion segment. The practice of short-segment fixation and fusion is particularly valuable in the lumbar spine, where a loss of motion segments and of the normal lordotic curvature can cause mechanical pain ("flat back syndrome").\(^9\)\(^15\)

Pedicle screws can still be used on vertebrae even if a laminectomy has been performed.\(^15\) No instrumentation is placed directly into the spinal canal, eliminating the risks of metal stenosis and iatrogenic spinal cord injury that occur with hook-rod systems.\(^14\) Sacral fixation is readily achieved with pedicle screws but is difficult to accomplish with hooks.\(^13\)\(^15\)\(^34\)

**Disadvantages of Pedicle Screw Instrumentation**

Pedicle screw fixation is technically demanding and can have a high complication rate.\(^1\)\(^2\)\(^3\)\(^4\)\(^5\)\(^6\)\(^7\)\(^8\)\(^9\) Instrument failure, wound infections, prolonged operating time, large blood loss, and expense are problems shared with other fixation systems for the thoracic and lumbar spine.\(^5\)\(^8\)\(^9\)\(^13\)\(^15\)\(^20\)\(^26\) A unique hazard of pedicle screw fixation is the risk to individual nerve roots if screws are misdirected. This risk can be reduced to acceptable levels or completely eliminated by careful preoperative planning and meticulous operative technique.\(^14\)\(^15\)\(^23\)\(^27\)\(^30\)\(^37\)

Screw fixation requires an intact pedicle and vertebral body for adequate purchase.\(^15\)\(^30\)\(^31\) Screws cannot be used in vertebrae if the pedicles or vertebral bodies are fractured or have been destroyed by tumor or infection. There is also a risk of failure if the instrumentation is used in severely osteoporotic bone.\(^15\)\(^23\)\(^31\)\(^36\)\(^39\)

Rigid internal fixation systems have been implicated in causing osteoporosis.\(^22\) Stress upon vertebrae causes normal bone remodeling and maintenance of optimum bone strength. Theoretically, reducing the normal forces placed upon the vertebrae with instrumentation ("stress shielding") can decrease bone remodeling and cause osteoporosis. However, in practice, the mechanical properties of instrumentation on spinal arthrodesis more than compensate for any device-related osteoporosis.\(^22\)

**Pedicle Anatomy**

Experience with the proper operative techniques and a thorough knowledge of regional pedicular and vertebral anatomy are critical to prevent iatrogenic root injury. The anatomy relevant to pedicle screw placement has been described in detail previously.\(^14\)\(^17\)\(^24\)\(^30\)\(^41\) The thoracic, lumbar, and sacral pedicles are oval-shaped and composed of a thick collar of cortical bone surrounding a core of cancellous bone.\(^14\)\(^15\)\(^17\)\(^24\)\(^40\) The narrowest portion of the pedicle is the transverse width, which limits the diameter of the screws that can be used.\(^14\)\(^15\)\(^17\)\(^40\)

The caudal pedicles progressively increase in size and become more medially angled in the lumbar region (Table 2).\(^17\)\(^41\) Pedicles in the lower thoracic spine, in the lumbar spine, and at the S-1 level are usually large enough to accept pedicle screws safely;\(^14\)\(^17\)\(^24\)\(^40\) however, pedicle sizes can be quite variable and should be assessed individually.\(^14\)\(^17\)\(^24\)\(^39\)\(^40\)

The pedicles at each vertebral level are angled differently in relation to the vertebral bodies. Generally, the pedicles at T-12 are perpendicular to the vertebral body; caudally, the pedicles become angulated more medially by about 5° per level. The L-5 and S-1 pedicles are usually angled 25° to 30° medially.\(^14\)\(^15\)\(^17\)\(^24\)\(^40\)

**Prevention of Root Injury**

Preoperative radiographic and CT evaluations are indicated to assess each patient’s unique anatomy and to detect pathology of the pedicles or vertebral bodies. Measurements of pedicle diameter, length, and angulation and vertebral body diameter are used to calculate the appropriate screw size and to plan the screw trajectory at each vertebral level. Careful fluoroscopic monitoring during pedicle preparation and screw placement is the most important tool to prevent screw malpositioning. Even spine surgeons with extensive experience with pedicle screw placement have a high rate of screw malpositioning if they rely only on external spinal landmarks.\(^15\) We depend on a C-arm fluoroscopic unit

---

*Modified from analysis by Zindrick, et al.\(^40\)*

† Numbers in parentheses indicate the range for each mean value.

**Table 2**

<table>
<thead>
<tr>
<th>Spinal Level</th>
<th>Mean Transverse Pedicle Width (mm)</th>
<th>Mean Transverse Pedicle Angles (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-10</td>
<td>6.3 (3.1-8.5)</td>
<td>4.6 (0.3-13.5)</td>
</tr>
<tr>
<td>T-11</td>
<td>7.8 (3.1-12.0)</td>
<td>1.2 (-6.0-9.5)</td>
</tr>
<tr>
<td>T-12</td>
<td>7.1 (3.0-11.0)</td>
<td>-4.2 (-17.4-14.5)</td>
</tr>
<tr>
<td>L-1</td>
<td>8.7 (4.5-13.0)</td>
<td>19.9 (6.3-14.5)</td>
</tr>
<tr>
<td>L-2</td>
<td>8.9 (4.0-13.0)</td>
<td>12.0 (5.8-17.5)</td>
</tr>
<tr>
<td>L-3</td>
<td>10.3 (5.3-16.0)</td>
<td>14.4 (8.0-23.5)</td>
</tr>
<tr>
<td>L-4</td>
<td>12.9 (9.1-17.0)</td>
<td>17.7 (5.5-27.5)</td>
</tr>
<tr>
<td>L-5</td>
<td>18.0 (9.1-29.0)</td>
<td>29.8 (19.4-44)</td>
</tr>
</tbody>
</table>

---

J. Neurosurg. / Volume 77 / December, 1992
that provides adjustable visualization during screw placement.

The operative procedures are performed with the patient under anesthesia without neuromuscular paralyzing agents to detect mechanical root impingement. Prior to rod placement, individual screws in their final position are touched with a nerve stimulator. A motor response indicates that the screw threads are in contact with a nerve root. This provides an easy supplemental maneuver to detect pedicle wall penetration.

If pedicle preparation or screw placement does not progress normally, the pedicle should be evaluated for disruption. The pedicle is probed to palpate for a defect in the cortical wall. A laminotomy and direct inspection of the pedicle are performed if a breach in the integrity of the pedicle is suspected. If a new postoperative radiculopathy develops despite these preventive measures, plain radiographic and CT studies are obtained to evaluate for screw malpositioning. Screws responsible for the symptoms should be removed and redirected or placed at a new site. The involved root should be decompressed.

**Instrumentation Selection**

A variety of pedicle screw systems are available for attaching the screws to plates or to threaded or non-threaded rods. We prefer the screw-rod systems to the screw-plate systems because of their ability to correct major spinal deformity, their greater structural rigidity, and the greater availability of bone surfaces for fusion. Screw-rod systems are adjustable and can also be used with hook fixation if desired.

We found no difference between the CD and the TSRH screw-rod instrumentation systems in terms of complication rates or instrument failure. Although these two universal instrumentation systems have many similar components, several differences exist. Both the CD and the TSRH systems have open screw heads which permit easy attachment of the rod to the screws. The CD system also has closed screw heads. The two systems have different crosslink mechanisms, rod surfaces, screw attachments, and locking mechanisms (Fig. 8).

One disadvantage of the locking assembly in the CD system is that the hex bolts must be twisted and broken off to obtain permanent fixation. This characteristic prevents readjustments and requires drilling to destroy the screw heads if the instrumentation must be removed. We prefer the TSRH system because the eyebolt attachments and locking nuts provide a secure fixation, yet readily allow the instrumentation to be repositioned or removed.

**Screw Selection**

The major screw diameter should be 70% to 80% of the pedicle diameter. Screws wider than 80% of the pedicle diameter can burst the pedicle apart or break through the pedicle wall. The flex, rigidity, or bending strength of pedicle screws are determined by the minor screw diameter. Narrow screws (<5.5 mm in diameter) bend and break easily and should be avoided for use in the adult lumbar spine.

Screws should be long enough to penetrate 70% to 80% of the depth of the vertebral body. Pull-out strength is determined primarily by bone quality, screw length, and major screw diameter and is linearly related to the depth of screw insertion. A bicortical purchase should be avoided because of the risks associated with anterior vertebral body penetration; however, a shallow purchase increases the risk of a screw pulling out.

**Hole Preparation**

We use a Steinmann pin rather than a drill to prepare the pedicle hole for screw placement. However, a variety of techniques are acceptable. This manual technique provides sensory feedback to the surgeon as the resistance of the bone changes. The pins are sized to create screw tracks that correspond to the minor diameters of the screws. These screw holes do not need to be enlarged by tapping in order to cut threads into the bone. Tapping does not improve screw pull-out strength.

**Screw Positioning**

Screws should be placed through the center of the pedicles into the vertebral body. Several trajectories are possible (Fig. 11). A medially angled screw...
Transpedicular screw-rod spinal fixation

trajectory confers several advantages over placing screws straight into the vertebral body: impingement upon the adjacent facet joint is avoided. Rotational stability is provided, longer screws can be used, and pull-out strength is improved.\(^1\)\(^,\)\(^6\)\(^-\)\(^12\)\(^,\)\(^24\)

On a lateral radiographic view, screws can be positioned in the vertebral body either parallel to or angled slightly toward the endplate. Screws should not penetrate the disc space since this can cause screw loosening. In patients with osteoporosis, angling the screws toward the endplate may be preferred since a more securepurchase for the screw threads can be obtained. However, the biomechanical advantages are minor. Either technique is acceptable.\(^1\)\(^,\)\(^3\)\(^-\)\(^6\)\(^,\)\(^12\)\(^,\)\(^24\)

The S1 pedicles are the preferred site for sacral screw fixation. Alternatively, sacral screws can be placed anterolaterally into the sacral ala.\(^1\)\(^3\)\(^-\)\(^6\)\(^,\)\(^21\)\(^-\)\(^24\) Pedicle screws can also be used in the thoracic spine if the pedicles are large enough. This is particularly useful for fractures involving the thoracolumbar junction.\(^3\)\(^,\)\(^6\)\(^-\)\(^12\)\(^,\)\(^24\)\(^-\)\(^26\) The techniques used to identify and prepare the thoracic pedicles for screw placement are identical to those used in the lumbar spine.\(^1\)\(^4\)\(^,\)\(^7\)\(^,\)\(^17\)\(^-\)\(^21\)\(^-\)\(^29\)

Rod Selection

Various rod sizes are available for use in children and adults. For the adult lumbar spine, we usually use rods \(\frac{1}{2}\) in. or 7 mm in diameter. Wide rods provide more rigid internal fixation and are particularly useful for correcting major deformities. In comparison, narrow rods are more easily contoured, may provide less stress shielding, and are especially useful if minor corrections or in situ fusions are planned. Crosslinking of the rods improves rotational stability, prevents rod migration, and inhibits lateral shift of the instrumentation.\(^1\)\(^-\)\(^6\)\(^,\)\(^15\)\(^-\)\(^26\)

Instrument Failure

Like other spinal instrumentation, pedicle screw systems are susceptible to eventual failure because of heavy loads and repetitive stresses placed upon the instrumentation.\(^5\)\(^-\)\(^12\) Due to the lumbar lordosis, the screws are subjected to large cantilever bending forces that can cause screws to break or bend.\(^1\)\(^3\)\(^-\)\(^12\)\(^,\)\(^21\)\(^-\)\(^26\)\(^,\)\(^36\)\(^-\)\(^39\)\(^,\)\(^41\) Since metal fatigue and can break, instrumentation must be viewed as a temporary measure for internal fixation while the bone graft is being incorporated.\(^1\)\(^3\)\(^,\)\(^19\)\(^-\)\(^23\)\(^,\)\(^26\)\(^,\)\(^36\) The surgeon must meticulously prepare the fusion site and depend on the development of an osseous union for long-term stability.\(^1\)\(^2\)

The sites of instrument failure depend on the characteristics of the individual patient and instrumentation. Screws loosen or pull out because fixation is lost at the bone-metal interface due to poor bone quality, shallow screw placement, or excessive stress on the screws. Screws bend and break at the junction of the collar and the first screw thread, where the minor and major screw diameters join.\(^1\)\(^1\)\(^4\)\(^-\)\(^15\)\(^,\)\(^23\)\(^,\)\(^4\) \(^4\) The instrumentation disconnects at the screw-rod interface due to weakening or loosening of the coupling mechanisms. Rods rarely bend or break, but that possibility exists if they are too narrow or excessively flexed.

As many as 20% of pedicle screw-plate systems have been reported to fail within 10 years, most within 2 years after surgery.\(^3\)\(^,\)\(^12\) This correlates closely with our findings regarding screw-rod systems. Importantly, half of all patients with instrument failures were asymptomatic with a solid fusion, and did not require treatment.

Failure of conventional wire-rod or hook-rod posterior instrumentation systems is usually associated with a nonunion.\(^1\)\(^3\)\(^-\)\(^6\)\(^,\)\(^18\)\(^-\)\(^24\) In contrast, pedicle screw systems are more prone to fail in association with a solid fusion.\(^23\)\(^-\)\(^36\) Revision of the instrumentation and fusion are required if instrument failure is symptomatic or associated with a pseudoarthrosis. We do not advocate routine instrument removal after fusion has occurred; however, long-term follow-up monitoring is mandatory to detect late complications.

Preventing Instrument Failure

Use of screws that are adequately sized and placed deeply within the vertebral bodies helps to minimize instrument failure. A bent screw is considerably less tolerant of fatigue;\(^1\)\(^4\)\(^-\)\(^15\) therefore, bending the screws should be avoided during reduction maneuvers or during attachment to the linking devices.\(^1\)\(^5\)

Destruction of a vertebral body that requires correction of vertical height or angular deformity places a heavy load and large bending moments on the instrument implants.\(^1\)\(^3\)\(^-\)\(^12\)\(^,\)\(^36\) These stresses can cause early implant failure. Thus, an anterior bone augmentation with a strut bone graft should be considered for patients with fracture, tumor, or infection who need a major spinal deformity corrected.\(^1\)\(^5\)\(^,\)\(^13\)\(^-\)\(^15\)\(^,\)\(^39\) Augmentation improves the stability and longevity of a short-segment pedicle screw fixation since the strut bone graft counteracts most of the major deforming forces associated with anterior column failure.\(^1\)\(^3\)\(^-\)\(^12\)\(^,\)\(^36\) A screw-rod implant that incorporates a longer level arm to include additional vertebrae without anterior augmentation can also be used.\(^1\)\(^5\)

Forces should be evenly distributed since excessive stress on any single screw can cause screw loosening.\(^1\)\(^5\) Loose screws can be salvaged surgically and larger screws should be placed unless they risk causing a pedicle fracture. Cancellous bone grafts or methyl methacrylate placed into a screw hole can restore a solid screw purchase.\(^1\)\(^3\)\(^-\)\(^12\)\(^,\)\(^36\)

References


J. Neurosurg. / Volume 77 / December, 1992

C. A. Dickman, et al.