CHAPTER

33

INTERNAL FIXATION WITH PEDICLE SCREWS

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There is a wide variety of internal fixation devices available for spinal disorders in which significant instability is present and fusion is indicated. So far, all systems have resulted in significant problems and complications; the spine plate and segmental pedicle screws were developed because of these problems. Currently there is a growing number of surgeons who are using the spine plate and pedicle screw system worldwide.

In this chapter, we are presenting our experience with the Variable Spine Plate (VSP) System developed by Dr. Arthur Steffee of Cleveland, Ohio.

Spin plates have been used for many years. Wilson plates and Meurig-Williams plates were designed to be attached to the spinous processes. Reimers also used similar spinous process plates in Europe. Sicard devised plates of synthetic material that were screwed to the posterior aspect of the sacrum and pinned to the spinous processes. Obviously, spin plates cannot be used when wide decompression of the spine is necessary; in general, they do not provide enough holding strength for reduction, realignment, or sagittal contouring of the spine.

Humphries, Hawk, and Berndt reported the use of slotted plates designed to fix and apply compression in anterior lumbar interbody fusion. Noncancellous bone screws are used to gain purchase in the cancellous bone of the vertebral bodies.

PEDICLE SCREWS

Boucher first described passing long screws through the lamina and pedicle into the vertebral body, and Pennel and coworkers reported satisfactory results using Boucher's method of screw fixation. In addition, Harrington and Dickson, McPhee and O'Brien, Sijbrandij, and Vidal and associates have all used screws through the pedicles along with Harrington instrumentation or its modification to achieve reduction and stabilization of spondylolisthesis.

SPINE PLATES AND PEDICLE SCREWS

Schöllner reported a technique of reducing spondylolisthesis using two pedi-
Some published reports on other fixation systems are among the following.

A. Pedicle screws and rods.
   1. Harrington and Dickson
   2. Kostuik, Errico, Gleason
   3. Long Beach system (Field, Wilsec, Zindrick, Widell, Thomas)
   4. San Francisco System (White, Zucherman, Hsu) (Fig. 33-1)
   5. Vermont system (Krag, Dykman, Pope, Frymoyer)
   6. Posterior Zielke instrumentation with transpedicular fixation

B. Pedicle screws, wires, and rods
   1. Luque (also developing a spine plate and pedicle screw system)
   2. White and associates

C. External fixation with pedicle threaded pins
   1. Mager (clinically used since 1977, consisting of two pairs of Schanz screws and an adjustable external fixation device, suitable for treatment of unstable spinal injuries and spinal osteomyelitis)

Zindrick and coworkers performed a biomechanical study of different pedicle screws currently available. The screws were inserted into the pedicles of fresh lumbosacral specimens; tension loads were then applied to the screws to the point of failure. Their conclusions included the following.

1. Screws with variable thread patterns gained better purchase if the large threaded areas are kept in the cortical bone of the pedicle. This point applied to the Steffee and the AO cancellous screws.
2. Larger thread diameters showed the best holding capabilities.
3. A modified awl making starting holes in the superior facet area allowed for more accurate pedicle entry than did drilling.
4. No significant difference was noted with tapping before screw insertion.
5. The second sacral (S2) pedicle provided the weakest fixation.
6. Force required to produce screw failure was inversely proportional to the degree of osteoporosis. Filling the pedicle with larger threads afforded better purchase, especially in osteoporotic specimens. Tapping was not beneficial in very osteoporotic specimens.
7. Methylmethacrylate cement significantly improved the holding power of all screws and was related to the amount and insertion technique used. The methylmethacrylate may leak into the neural canal through defects in the pedicle produced by the screw or tap threads.

VARIABLE SPINE PLATE/PEDICLE SCREW SYSTEM

Steffee developed titanium plates with screw slots containing “nests” to allow both adjustment and rigid fixation of vertebrae. The plates can be contoured to control the sagittal curve of the spine. The pedicle screws are made with two types of threads: cancellous bone threads and machine threads on the shank to accept tapered nuts.

The variable spine plate (VSP) system allows alignment and stabilization of the spine while fusion takes place. In unstable spondylolisthesis, anatomic reduction is facilitated. After wide decompression and exposure of fusion bed, pedicles are accurately located, reamed, and tapped, and two screws are inserted into each vertebral body. The plates are contoured and placed over the screws. The tapered nuts are tightened down to correct sagittal alignment. Bone graft is placed in the lateral gutter over the transverse processes. In osteoporotic bone, methylmethacrylate cement is injected into the vertebral body through the pedicle to anchor the screws. Steffee is developing a molly bolt to allow good fixation without using cement. Some advantages of the VSP system include:

1. Segmental rigid fixation
2. Good sacral fixation
3. Good control of sagittal curve
4. Allows reduction of spondylolisthesis or retrolisthesis
5. Avoids spinal canal (in contrast to lamina wires and hooks, which are within the canal)
6. Applicable in osteoporotic spine
7. Allows early mobilization and eliminates postoperative bracing
8. Ease of nursing care

Some disadvantages are:
1. Technically difficult
2. Increased bulk of metal implant
3. Implant prominence
4. Implant irritation
5. Implant failure
6. Weakening of facet joints of the lowest unfused segment
7. Increased operative time
8. Increased infection risk

POSTEROLATERAL FUSION USING SPINE PLATES AND PEDICLE SCREWS
Preferred Technique

The patient is placed prone in a knee-chest position on the Andrews frame with the abdomen free. A midline incision is made, and the paraspinal musculature is elevated off the spinous processes and laminas. A point is made to preserve the interspinous ligament and facet joints at the level above. The identification of the appropriate level should be made by morphology or x-ray film.

Laminectomy and decompression are carried out. The dura and the nerve roots are carefully protected from injury. Extensive decompression, including discectomies, foraminotomies, and facetectomies, is performed as indicated.
The dura and nerve roots are then thoroughly inspected. The nerve root canals are gently examined in their entire length and width, using a smooth probe of adequate length. (A "hockey stick" or "foraminal probe" may serve this purpose.) Each nerve root should be followed out past its foramen, to be sure that it is free from lateral compression or impingement.

PREPARATION FOR POSTEROLATERAL BONE GRAFT BED

The facets and transverse processes are exposed. The Wiltse retractors are placed on the tips of the transverse processes. At L5, we prefer to preserve the attachment of the iliolumbar ligament and use a Meyerding or Taylor retractor on the posterior iliac crest for exposure. Soft tissue is removed from the posterior aspect of the transverse processes only. The intertransverse membrane is left intact. The vessels in the caudal axilla of the transverse process lateral to the pars may be cauterized before dissecting in this area.

A small curved curette is used to make a groove in each transverse process longitudinally to its axis. Perpendicular strokes are then made cephalad and caudal to complete the decortication; ¼ inch chisels are used to decorticate the lateral faces of the superior facets, the pars, and the sacral ala. A large flap of bone is taken from the sacral ala and folded over toward the L5 transverse process. (Fig. 33-2.)

PEDICLE SCREW INSERTION

To locate the pedicle several landmarks may be used.
1. The transverse process generally corresponds to the level of the pedicle in the lumbar spine.
2. The caudal tip of the inferior facet.
3. The ridge or junction of the facet, transverse process, and lamina. (Fig. 33-3.)

The pedicle may be palpated with a probe or visualized directly if the exposure is adequate. We have devised pedicle guides to facilitate accurate screw placement (Figs. 33-4 through 33-7). A ½ inch burr is used to penetrate the posterior cortex, and a pedicle probe or ganglion knife is used to advance the burr hole into the pedicle and the vertebral body. The probe should follow a path of least resistance into the cancellous bone (Figs. 33-8 through 33-10).

A pedicle sounder probe or a depth gauge is used to palpate the hole to be sure it is surrounded 360 degrees by bone (Figs. 33-11 and 33-12). Common errors are breaking through lateral vertebral body cortex, pedicle comminution, entering the spinal canal, or entering the lateral canal.

The hole is then partially tapped with a cancellous bone tap. Using the screw wrench, the pedicle screw is inserted until the large cancellous threads are completely within the vertebral body and pedicle. The screw should be directed slightly medially into the cancellous bone of the vertebral body. If the bone stock is poor, methylmethacrylate cement may be injected into the screw hole before screw placement.

Screw placement is begun at the most...
Fig. 33-3 Landmarks to locate pedicle. A, Transverse process corresponds to the level of the pedicle. B, Caudal tip of the inferior facet. C, Junction of facet, transverse process, and lamina.

Fig. 33-4 Two types of pedicle guides. A, Curved plate and B, pedicle aiming device with probe sleeve.

Fig. 33-5 Using the two types of pedicle guides to improve accuracy.
Fig. 33-8 Hole is made to posterior pedicle cortex.

Fig. 33-9 Poise or drill is used to advance bur hole into pedicle.

Fig. 33-7 Curved probe or Burr is used to direct probe or drill into pedicle.

Fig. 33-6 Aiming device with probe or drill is used to locate pedicle.
Fig. 33-10 Pedicle probe is advancing through pedicle into vertebral body.

Fig. 33-11 Pedicle sounder probe or depth gauge is inserted into pedicle.

Fig. 33-12 Hole in pedicle is probed with depth gauge to be sure that it is surrounded by bone 360 degrees.
Fig. 33-13 Pedicle screw is inserted until the large cancellous threads are within the bone. (Shown from left upper to left lower levels.) Plate is then placed over the screws with nuts applied anteriorly and posteriorly to lock plate in place. (Shown on right side.)

accessible pedicle, but sacral screws are placed last. The screws should be inserted perpendicular to the longitudinal axis of the spine at each level to prevent subsequent screw bending or increased screw torque movement.

A properly placed initial screw can serve as a guide for the remaining screws. The sacral screw is inserted last because there is more suitable bone stock, allowing more variable screw placement. Great care is taken to keep the screws linearly arranged for plate placement (Fig. 33-13).

A tapered nut is advanced with the flat surface up until the round surface is in contact with bone. A malleable template (aluminum) of the same length as the plate is placed against the flat surfaces of the nuts. The template serves as a guide to contour the plate using a plate bender. (We have been using an A-O plate bender with good results.)

The plate is then placed over the screws. It should slide easily over the screws onto the nuts. It is important not to strip the threads by forcing the plate down.

Desired distraction may be applied using screw alignment rods on adjacent screws, screw alignment bar or T-handle nut wrenches. Overdistraction can cause pedicle fracture and screw loosening caused by uneven pedicle pressure. We also suspect this may cause gradual erosion of screw threads through the pedicle in some cases, and cause radicular symptoms. Currently, we do not distract unless there is a specific indication to do so. The upper tapered nuts then are applied to tighten and lock the plate in place. When indicated, sacral buttress clamps and additional screws may be used to reinforce sacral fixation (Fig. 33-14).

Bone graft is positioned over the de- corticalized surfaces in the lateral gutter.
(using a Russian forcep or a teaspoon), either before or after the plate is in place. The lateral neural canals are explored to assure patency and that there is no encroachment from bone graft chips.

The opposite-side screws are next applied in a similar manner. The template is again used to contour the plate, because the contour often varies on the right and left sides.

A lateral x-ray film is taken to assure intrapedicle placement of the screw and depth of sacral penetration by the SI screws. It is desirable to have slight penetration of the SI screw to ensure that the anterior sacral cortex is engaged.

The portion of the screw above the upper nut is then removed with a bolt cutter. Gelfoam or fat grafts are applied over the exposed dura or nerve roots if desired.

Ambulation is begun on the first postoperative day with the patient in a lumbosacral corset; the corset is worn for a minimum of 3 months. Patients are instructed to limit their activities to less than 1 mile of walking per day and minimize sitting for 3 to 4 months.

Some patients who have been very active appear to have loosened the screw-bone interface and have developed back, hip, and leg pain. This usually resolves with fusion solidity.

Experience in Spine Plating with Pedicle Screws

Between August 1984 and October 1985, 76 lumbar spine fusions, using Steffee's VSP spine plate and pedicle screw system, were performed at St. Mary's Hospital in San Francisco. Follow-up ranged from 10 to 24 months, with a mean of 15.4 months. Age of the patients ranged from 24 to 76 years, with a mean of 47 years. There were 46 males and 30 females.

The diagnoses for these cases included:

- Disc herniation and instability 43%
- Spinal stenosis with instability 24%
- Segmental instability 11%
- Spondylolisthesis with instability 7%
- Pseudarthrosis 7%
- Herniated disc and stenosis 7%
- Spine fracture dislocation 4%
- Herniated disc, instability, and poliomyelitis 1%

The numbers of levels ranged from one to five, with an average of 2.5.

Of the 76 patients, 49 (64.4%) had had previous procedures in the area operated. In three cases only chemonucleolysis was performed. In addition, 38 of the 76 patients (50%) were involved in worker's compensation or litigation.

Operative time ranged from 2.5 to 6 hours, with an average of 3 hours 45 minutes. Plate size ranged from 2 to 5 slots bilaterally with a mean of 2.7. The number of pedicle screws used ranged from 4 to 12, with a mean of 6.4. There were two spine surgeons present during each of the procedures, and all procedures were performed by the four authors of this chapter.

We rated our results as follows:

- Excellent: No symptoms
- Good: Marked improvement
- Occasional pain
- Occasional use of pain medications
- Fair: Some improvement
- Need for pain medications
- Significant functional restriction
- Poor: No change in symptoms or worse

Overall results according to the above criteria follow:
of marked preoperative spinal instability. Both had good ultimate results.

Two other infections were found within 2 months after surgery. Both were indolent anaerobic pathogens. Initially, they were treated unsuccessfully with 6 weeks of intravenous antibiotics. Both required removal of the metal implants and delayed wound closure. The infection resolved after implant removal and delayed wound closure.

The infection rate using this metal fixation has been higher than other fusion techniques in our hands. This would appear to be due to increased operative time, the larger volume and surface area of the implant, and high percentage of revision cases in this series. We recommend such infection-minimizing measures as laminar airflow, sterile hoods, frequent irrigation, and IV antibiotics for total joint arthroplasty.

There were 16 patients with one or more broken screws. Three patients were involved in moderate trauma. All three were doing well before the traumatic episodes. Two of the three were improved after removal of metal implants. So far, seven patients with broken screws required reoperation. Screw failure occurred mostly in our younger patients and is probably related to increased activity level and firmer grip at the bone screw interface in younger, less osteoporotic patients. The screws failed at either end of the plate; 70% were at the sacral end.

The incidence of screw breakage was unacceptably high in our series. Recent changes in screw configurations already have been instituted; we expect that this will minimize the complication.

The height of the nuts has also been reduced recently. The resultant lower profile for the hardware should obviate the occasional complaints we have had of
Eight of our first 30 patients developed leg pain 1 to 2 months after surgery. This was presumably due to nerve-root irritation and was relieved by selective nerve-root blocks, epidural blocks, or with application of a corset or brace.

This problem occurred in the first portion of our series, when we locked the instrumented vertebrae in distraction. We suspect that distraction places a constant unidirectional torque on the screw against one wall of the pedicle, as shown in the diagram (Fig. 33-15), possibly resulting in erosion, migration of the screw or pedicle fracture (Fig. 33-16). Pedicle fracture was visualized during surgery in one osteoporotic patient. It is important to remember that distraction at one segment causes contraction of adjacent segments that are instrumented.

**Distraction**

- Narrowing
- Stenosis
- Screw bending
- Pedicle fracture

This mechanism is illustrated in Fig. 33-17; as distraction is applied at one segment the adjacent segment is compressed, causing disc narrowing and foraminal stenosis.

Appropriate contouring of the plate and proper screw alignment should produce a screw plate angle of 90 degrees. Screw plate angle may be an important factor in generating eccentric torque stress against the pedicle. The greater the deviation from the perpendicular, the greater the torque generated when the plate is locked to the flat surface of the nuts, as illustrated in Fig. 33-18.

In similar situations, especially over the sacral curve, the screw bends and becomes weaker as it is locked to the plate (Fig. 33-19). Occasionally, the nuts do

![Fig. 33-15](image-url)  Distraction places a constant unidirectional torque on screw against one wall of pedicle.

![Fig. 33-16](image-url)  Pedicle fracture or erosion may occur when distraction is applied and a constant unidirectional torque created on the screw against one wall of the pedicle.

![Fig. 33-17](image-url)  When excessive distraction is applied at one segment, the adjacent segment may become compressed, causing disc narrowing and/or foraminal stenosis.
not lock until the screw finds a stable position, especially over a sharply curved plate. Foraminal stenosis may be produced by this mechanism (Fig. 33-20).

It is important that the nerve root foramina are examined and gently probed after the instrumentation placement to be sure that no stenosis is produced and that bone graft has not been squeezed into the lateral neural canal by the plate.

Fig. 33-18 Angular forces are created as nuts are locked eccentrically to plate.

**Problem of Stress Transfer to Adjacent Levels**

We are seeing some patients with problems at the level adjacent to the fusion in the forms of disc degeneration, facet syndrome, and hypermobility. The latter is commonly seen on bending films, although frequently it is asymptomatic. To insert the screw accurately, the normal facet at the first unfused segment is often violated. The capsule and the inferior one fourth of the inferior facet are usually removed, presumably weakening the posterior column of the level above (Fig. 33-21). The frequency and extent that this will weaken the adjacent motion segment are unclear with the short follow-up now available. Increased rigidity of the fixation is also expected to increase stress risers in the adjacent segments. We currently place the plates and screws lateral to the facets to avoid weakening the unfused levels.

Fig. 33-19 A sharply curved plate, especially over the sacrum, may cause screw to bend and become weaker as nuts are locked to plate.

Fig. 33-20 Nuts do not lock until screw finds a stable position over a sharply curved plate. Foraminal stenosis may be produced by this mechanism.
We have found it seemingly useful and logical to perform discograms and saline acceptance tests of adjacent levels before all fusions to prevent ending a fusion adjacent to a degenerated, potentially painful segment. This concept is conjectural at this time. However, we are documenting not infrequent radiologic and clinical deterioration in these adjacent segments.

SUMMARY

In spite of the problems we have encountered, the VSP System provides the following.

1. Adequate fixation, even when the posterior elements are totally removed, occurs.
2. It allows good control of sagittal curve and excellent three-dimensional realignment. Most other instrumentations result in flattening of the lumbar lordosis and resultant hyperextension of the upper segments. We believe it is important to place the vertebra above the fusion in the "anatomic angle" of the spine.
3. Superior sacral fixation exists.
4. It allows good reduction of spondylolisthesis when it is necessary (Figs. 33-22 to 33-26).
Fig. 33-24 Posterior fusion is performed after reduction and fixation.

Fig. 33-25 Interbody fusion is another option.

Fig. 33-26 Interbody fusion may be combined with posterolateral fusion.

Fig. 33-27 Reduction of retrodisplaced vertebral fracture fragments using an impactor carefully positioned anterior to dura.
5. It provides excellent internal fixation for unstable fracture dislocation without sacrificing additional normal levels (Figs. 33-27 and 33-28).

6. It permits early mobilization and ease of postoperative nursing care.

7. We expect fusion rate to be improved because of the rigid fixation.

Younger patients seemed to have slightly less favorable outcome, presumably due to harder bone and increased activity level resulting in more-hardward problems, that is, breakage.

The procedure is time-consuming and technically difficult, with significant hardware problems. The latter will hopefully be reduced by advances in design. One should definitely have thorough training in the technique before performing the procedure. An equally qualified assistant is also important.

In general, after this brief experience, we believe that the VSP System has a useful role in spine surgery when used selectively.

REFERENCES


For decades spine surgeons have theorized that the ideal lumbar spine surgery for disc disease would be some form of internal fixation device that would hold the operated segment in anatomic alignment while fusion occurred 100% of the time. Such a fixation device would need to be easy to insert and remove, and would carry no significant complications. We see in this book three devices that seem to meet those criteria.

My experience with over 100 clinical cases of pedicle screw fixation leads me to maintain caution in the use of pedicle screw fixation.

The placement of pedicle screws is not without danger. The pedicle can and does break with insertion or long-range toggle of these screws. New signs and symptoms of nerve root irritation develop for unknown reasons weeks to months after insertion. Pedicle screws break. New heavy stresses are placed on the segment adjacent to this immediate rigid fixation device. Adjacent segments can be weakened by the insertion of the device.

Although there is a definite valuable place for these new pedicle screw fixation devices in lumbar spine surgery, I have not found them to be the answer on any routine basis. My clinical success rate was every bit as good with the use of Knodt rods and Harrington rods. The complications with the use of metallic internal fixation probably outweigh the value of increased fusion rates and immediate stability.

The internal fixation devices improved our success rates before we understood spinal stenosis and the need for adequate decompression. The decompression remains the most important aspect of spinal stenosis surgery. A fusion simply decreases the amount of low back pain a patient will experience after a decompression and disc excision. The fusion will prevent postoperative settling and spinal stenosis, which does not have to be a problem with adequate decompression. The fusion may prevent postoperative recurrent herniated discs and recurrent spinal stenosis.

A lumbar decompression and disc excision, when done well, has only a 5% to 10% likelihood of failure and the need for a second operation. To obviate this 10% repeat operation rate, it is probably not worth the risk of a major internal fixation fusion on 100% of lumbar disc surgery patients.

In certain patients such as those with osteoporosis, obesity, spondylolisthesis, multiple failed surgeries, and trauma the failure rate with decompression alone is much greater than 10%. Internal fixation is much more reasonable and, in fact, often necessary for success in some of these patients. One should, however, be very familiar with the device that will be used and take special training in the use of the device before using it surgically.

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