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Complications of Transpedicle Spine Fixation

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INTRAOPERATIVE COMPLICATIONS

Neurologic

Neural injury is of particular concern when pedicle screws are used because neurologic structures are close to the pedicle and inserting the pedicle screw instrumentation is often technically demanding. Neural injuries can occur intraoperatively during hole preparation and screw insertion from burring, drilling, probing, curetting, misdirecting the screw out of the pedicle, or using a screw with a diameter that is too large. Intraoperative injuries such as screw stripout, pedicle fracture, and bone graft displacement by a longitudinal plate, can also result during hardware assembly. These are less likely to occur with articulated screw-and-rod systems with three-dimensional adjustability, such as the Ölerud,[31] the fixateur interne,[6,7] and the Vermont spinal fixator.[17,23,28] Finally, postoperative injuries can occur from late screw cutout or pedicle erosion. These injuries include dural tears, nerve root irritation or mechanical damage. and lumbar or lumbosacral plexus injuries.

Dural tears can be caused by misdirected screws or other instruments inserted medial to the pedicle. Cerebrospinal fluid pressure may keep the tear open and lead to pseudomeningocele or fistula formation. This increases the risk of infection or neurologic compromise. The misdirected screw probably should be removed as soon as possible. although the exact level of urgency is not clear. Surgical closure of dural tears is recommended whenever feasible and especially when nerve rootlets are extravasated. The extravasated rootlets should be returned to within the dural sac. If leakage of cerebrospinal fluid persists, a subarachnoid catheter inserted percutaneously to relieve cerebrospinal fluid pressure should allow dural healing in many cases. Rarely, a patient may have to be returned to the operating room for surgical closure.

The nerve roots are the structures that are most at risk for damage by screws placed out of the pedicle. Each nerve root passes along the medial and caudal cortices of the pedicle, then courses out through the superior third of the intervertebral foramen to become the spinal nerve, which runs lateral to the subjacent pedicle. Thus nerve root damage can occur by screw penetration at any of these sites (although screw penetration by no means necessarily causes nerve damage).

How best to reduce the risk of intraoperative pedicle cortex penetration is not clear. The use of anteroposterior and lateral radiographs is not helpful. In a cadaver study by Weinstein and colleagues,[46] anteroposterior and lateral view C-arm monitoring during screw placement resulted in a 21% incidence of pedicle penetrations, and 60% of these were not detected on these x-ray views. Roy-Camille and coworkers,[34] using anteroposterior and lateral x-ray films after screw placement, reported a 10% rate of screws out of the pedicle. Davne and Myers[5] reported lateral cortical breakthrough to be their most common technical problem. However, in contrast to this, using a coaxial oblique x-ray view along the pedicle (described in Biomechanics of Transpedicle Spine Fixation) Krag and associates[21] had an out of pedicle rate of only 0.5% (1 of 212 screws).

Another alternative is sufficient laminectomy to allow palpation and direct visualization of the medial pedicle wall and nerve root, although this still does not allow visualization of lateral cortical penetration. The pedicle may fracture with insertion of a screw with a diameter too close to that of the pedicle. Tapping may help prevent this, although the use of a smaller screw is preferable. Morphometric studies have shown considerable variations in diameter, length, shape, and angulation of human pedicles.[19, 22] Appropriate preoperative radiographs and computed tomographic scans are helpful in recognizing these pedicle features, especially in a spine that is abnormal or was previously operated on, in which bony surface landmarks may be difficult or impossible to identify reliably.

Late screw cutout from pedicle erosion or fracture can also injure the nerve roots. The involved screw should be removed if symptoms are significant. In one clinical study, eight of 30 patients developed leg pain 1 to 2 months after variable screw-plate placement.[56, 58] This was presumably a result of nerve root irritation and was relieved by selective root blocks, epidural blocks, or application of a brace. This problem occurred early in the series when vertebrae with instrumentation were locked in distraction, which probably led to pedicle erosion or fracture.

Parts of the lumbosacral plexus are located anterior to the sacral ala. The lumbar plexus is found anterior to the L5–S1 disc and sacral promontory. Therefore, anterior perforation of the sacral cortex may injure either of these structures. Such injuries are prevented by limiting the depth of penetration beyond the sacral cortex or by avoiding it altogether. Mirkovic and associates[28] believed that the potential for lumbosacral trunk impingement or injury is as high as 55% with an S1 screw insertion through the cortex at a lateral angle of 45 degrees. They proposed that a more medial 30-degree S1 insertion is safer because of a wider safe zone. Dohring and Krag[8] found that the safe zones for both anterolaterally oriented alar screws or anteromedially oriented promontory screws were unusably small and pointed out that the neurovascular structures near the midline were less important than those in front of the ala. In addition, they showed that anteromedial screws have a bone-screw interface stiffness that is twice as great as that of anterolateral screws.

The question of whether the risk of neurovascular damage from anterior cortical peneration is large enough to offset the presumed benefit of the greater strength that is probably achieved has not yet been answered. However, risk reduction can be achieved by certain intraoperative steps. Steffee[41] recommended inserting a Steinmann pin slowly and carefully to and then through the anterior sacral cortex using a mallet. At each strike of the mallet, the sound pitch, the vibration detected by the fingertips holding the pin, and the amount of pin advancement are monitored: at pin contact with the anterior cortex, the pitch rises, the vibration increases, and the advancement slows.[40] At cortical breakthrough, the pitch and vibration are reduced. At this point, the Steinmann pin is advanced no further. The intent is to engage the anterior sacral cortex without perforating the periosteum (although Weinstein and colleagues[47] recommended inserting the screw tip 1 to 2 mm anterior to the cortex). This technique may be less reliable in osteoporotic bone. In more than 500 cases of bicortical sacral screw fixation, the authors have had no complications related to screw insertion using this method.

Using a drill in the sacrum should be avoided. Using a tap when the anterior cortex is crossed should also be avoided. Mirkovic and coworkers[28] recommended the use of self-tapping screws with recessed flutes. They also advised palpating the medial side of the hole with the foot of the depth gauge until it emerges on the anterior cortex. The screws inserted past the sacral alar anterior cortex should not be sharp, but rather blunt tipped, and should have tapered distal threads.

During spine surgery in which pedicle screws are used, neurologic complications can be caused by events other than pedicle screw insertion. They may occur when a spinal deformity such as scoliosis or spondylolisthesis is corrected. The potential for such a complication is greater with pedicle screw systems because of the improved mechanical control that they provide of vertebral realignment. In the case of scoliosis or spondylolisthesis, distraction may result in excessive stretching of neural elements. In the case of spondylolisthesis, the risk of nerve root compression from osteophytes, fibrous tissue, and disc material is increased, especially with long-standing higher-grade spondylolisthesis and secondary changes such as severe foraminal stenosis. Meticulous examination, canal exploration, and adequate decompression must be performed before and after reduction and instrumentation. If reduction is planned, it should be carried out gradually and carefully.

It is important to remember that neural injuries are known complications of spine surgery even when no implants are used. During fracture reduction and stabilization, the spinal cord, the conus, and the cauda equina as well as the nerve roots may be injured further, especially when they are already inflamed and swollen from the initial injury. All neural elements are sensitive to manipulation and retraction. Increased epidural bleeding may also compound the problem. Spinal cord or conus retraction should be avoided. Instead, a pedicle may be removed or an alternative surgical approach used. Other injuries can occur in the course of spinal canal exploration, decompression, and fracture reduction. Nerve root compressions from bone graft and even paraplegia from postoperative epidural hematoma have been reported.[32, 42]

Vascular

Pedicle screw strength has been shown by Krag and colleagues[18, 20, 22] to increase gradually with depth of vertebral penetration up to the anterior cortex. The strength of screw placement through the cortex was not tested. The authors conjectured that a closer approach by the tip of the screw (or drill or tap) to the anterior cortex presented a greater risk of unintentional penetration through it. To reduce this risk, they described an intraoperative radiographic method ("near-approach" view).[20] Anterior cortex penetration carries the risk of injury to vascular, visceral, neural, and ureteral structures. The depth or distance of anterior perforation, the mobility of the adjacent structures, the size of the screw, and the sharpness of the screw thread or screw tip all have an influence on this risk.

The incidence of anterior perforation by pedicle screws is not known. It is probably higher than usually appreciated. Whitecloud and associates[31] and Krag and coworkers[20] showed that a true lateral roentgenogram is not accurate for detecting pedicle screw penetration of the vertebral anterior cortex. Whitecloud and associates[51] showed that the greatest discrepancy between roentgenographic appearance and actual penetration was for screw insertions at the L4 and L5 levels. At 50% apparent depth of penetration on lateral roentgenograms, the screw may be safely assumed not to have perforated the anterior cortex. At 80% apparent depth, there is a 30% probability of cortical perforation at L4 and a 10% probability at L5. At 100% apparent depth, there is almost a 100% probability of perforation.

Inadvertent puncture of a major blood vessel often causes bleeding, which may result in death. Formation of a hematoma, a false aneurysm, or a fistula may also occur. Thrombus formation and embolism[1] may result from vascular irritation by the part of the screw inside the blood vessel.

Perforation of an artery may result in rapid hemorrhage, which can be fatal if an emergency laparotomy is not performed to repair the vessel. Injuries to the aorta occur at or above the L4 level. Injuries to the common iliac arteries can occur at L5 or S1 from perforations of the anterolateral cortex.[1] Much smaller arteries are present at the midline than at the alar portion of the sacrum.[8]

In the case of venous perforation, the intravascular pressure may affect the outcome. Intravenous pressure is influenced by different patient positions. Wayne[45] showed that the lowest pressure is found with the patient in the tuck position or knee-elbow prone position. Lower intravenous pressure results in less bleeding. Anda and colleagues[1] showed that the inferior vena cava and common pelvic veins have large transverse diameters and lie closer to the vertebral cortex than do the arteries. These major venous structures form a broad band. Their walls are much thinner than the walls of arteries and thus they are probably injured more frequently in spine surgery. Injury to both a vein and artery may result in arteriovenous fistula. Anda and coworkers[1] demonstrated six typical configurations of the vascular anatomy to explain the types of vascular complications seen at the L3–L4 and L4–L5 levels. They also showed the transverse prevertebral vascular anatomy at the L5–S1 level. Usually at the L3 level the vena cava and the aorta have not divided, so at this level a right pedicle screw perforation tends to injure the vena cava and a left pedicle screw the aorta. Arterial or venous injuries can occur at the L4 or the L5 level, although the venous injuries are probably more likely.

Visceral

In addition to vascular and neural structures, visceral and ureteral structures can also be damaged by anterior cortical penetration by pedicle screws. The sigmoid colon is located anterior to the L5, S1, and S2 levels. The colon with its mesentery enters the pelvis from the left and remains mobile at the level of S1 and S2. At about the S3 level, the mesentery is no longer found and the rectosigmoid colon is located directly over the sacral surface anteriorly.[28] Bowel perforations can occur with deeply inserted sharp probes, drill bits, depth gauges, taps, and screws and may cause peritonitis. Gas-filled intestine was found by Anda and colleagues[1] to be located closer to the spine when the patient was in the prone position than in other positions. Presumably, sharp instruments and pedicle screws may perforate an air-filled gut more readily than a deflated gut not only because the former is located more posteriorly, but also because it has a larger diameter and its wall is under more tension. In spine surgery, most gut injuries occur at the L5–S1 level.[15, 37–39]

TECHNICAL COMPLICATIONS

In addition to screw penetration through the cortex of the pedicle or the anterior part of the vertebral body, other technical problems encountered in the use of pedicle screw instrumentation include screw breakage, bending, loosening, or cutout; nut loosening; coupling failure; rod breakage; and insufficient screw length, size, or thread type.

The design, material, and manufacturing methods for screws may each contribute to early failure of the implant. In the case of the Steffee system, screw failure was common with the early-generation devices. Steffee and colleagues reported eight implant problems out of 128 cases.[42] These included screw breakage, loosening, and migration. Zucherman and coworkers reported broken screws in 23% of 77 cases in an early series.[56] Screw breakage seems to occur more commonly with greater intervertebr motion, a greater disc height, or less anteri

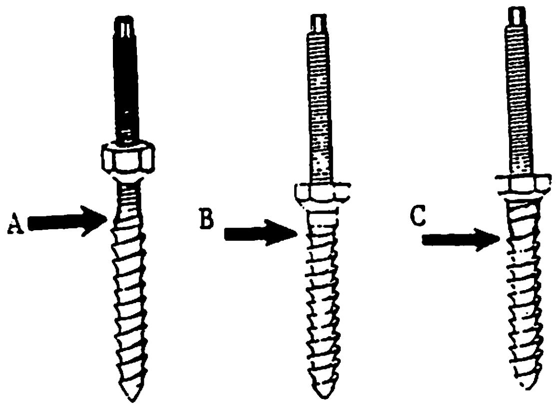


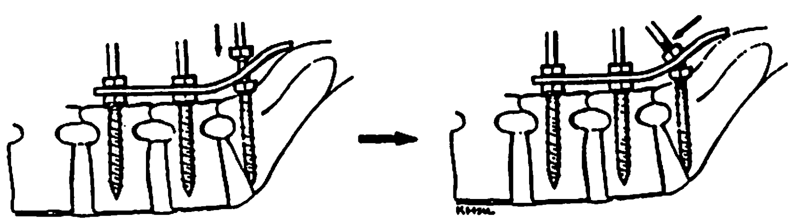
Figure 1. A. With the first-generation screw, which did not contain an integrated nut, failure occurred at the junction of the bone and the machine threads. B. With the second-generation screw, which contained the integrated nut, failure occurred at the junction of the bone thread and the integrated nut. C. With the third-generation screw, which has a tapered root diameter in the bone thread area adjacent to the nut, failure occurs at the end of the taper.

column load sharing. These circumstances probably contribute to greater stresses on both the screws and the screw-plate junction. In another study of the Steffee system, Davne and Myers[3] reported screw breakage after 4.3% of their 533 surgical procedures (1.1% of the 2642 screws placed). Screw design improvements explain the higher rate of breakage early in the series and the reduced rate later in the series.[44] The first-generation screw (Fig. 1A), which did not have an integral ventral nut, typically failed at the junction of the bone and the machine threads. The second-generation screw (Fig. 1B), which did have an integral nut, typically failed at the junction of the bone thread and the nut. The third-generation screw (Fig. 1C) has a root diameter that gradually tapers down from the nut to a point partway along the screw shaft and then does not decrease further. For this screw, breakage typically occurred at the end of the taper. Anterior or posterior interbody bone grafts probably reduce stress on the implant. Yashiro and colleagues[53] showed a 14% screw breakage rate with posterolateral grafts and no breakage with posterior interbody grafts. Tradeoffs between the increased morbidity from the additional surgery and the biomechanical benefits remain to be established. Also, improvement of implant design to reduce screw breakage without additional grafting is another avenue that remains open.

It is commonly assumed that a secure connection between the screw and the plate or rod leads to a greater risk of fatigue failure, although this has not yet been established. Certainly, systems with less secure connections are also subject to this problem. In a series of 84 patients treated with the Roy-Camille system of plates and unlocked screws, Roy-Camille and colleagues[34] reported 25% of the distal screws broke 5 to 24 months after stabilization of lumbar fractures and that sacral screws failed most frequently. In his series of 101 cases treated with a similar system, Louis[25] reported that eight screws broke and six screws loosened in the first 36 months after surgery. It is unknown whether implant failure causes nonunion, whether nonunion causes implant failure, or whether no cause-and-effect relationship exists.

It is important not to weaken the screw by bending it.[29] For implant systems in which the screw is locked to the plate, this can happen if the screw is not locally perpendicular to the plate (Fig. 2). Even if plastic deformation of the screw does not occur, the greater the deviation from the perpendicular, the greater is the cantilever bending load applied to the screw when the locking nut is tightened (Fig. 3). In actual clinical practice, perpendicular alignment is rarely achieved. Matsuzaki and coworkers[26] demonstrated that the application of a 32-kg force at a distance of 27 mm from the plate resulted in a 5-degree deviation of the screw away

Figure 2. Variance of plate screw angle from 90 degrees can result in screw weakening and bending.



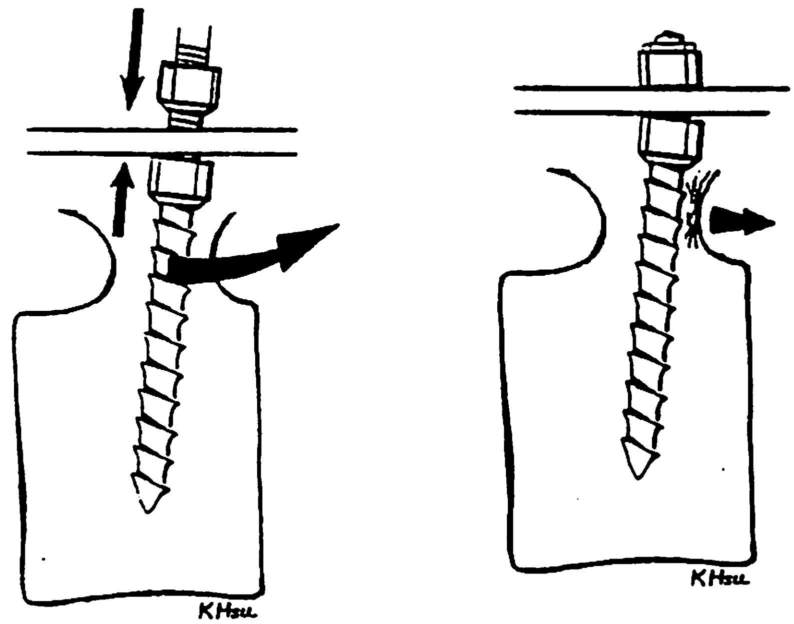


Figure 3. Tightening of the nuts when the screw is set in position varying from 90 degrees in relationship to the plate results in a unidirectional torque that may cause screw weakening and delayed pedicle erosion or fracture.

from perpendicular. Thus, if the screw-plate malalignment is 5 degrees, after the lock nut is tightened the screw tip is exposed to a load of 32 kg. To reduce this problem, they recommended a number of practical improvements.[26] One of these was to increase the width of the slot by 1 mm to accommodate screws that are less than perfectly aligned. Another recommendation was to develop a spherical "nest" in the plate or to recess both the upper and lower surfaces of the plate to allow more choice in alignment of a screw, the integral nut of which would have an upper surface that is spherical (Fig. 4).

Rather than cause screw bending, tightening of the locking nut on a nonperpendicular screw may instead change the intervertebral alignment, which may result in foraminal stenosis (Fig. 5). It is important that the nerve root foramen be examined and gently probed after completion of the instrumentation to be sure that no stenosis is produced and also that bone graft has not been squeezed into the lateral neural canal by the plate. If questions remain, the nerve root should be inspected carefully and adequate decompression performed, if necessary. The nerve root is followed out past its foramen to ensure adequate decompression. Steffee recommended nerve root decompression until a 6-mm probe can be passed through the neural foramen.[42, 44]

The plate should be contoured appropriately to maintain normal lumbar lordosis and to prevent undesirable hardware prominences, especially over the sacrum. Wedged washers (Fig. 6) are helpful in obtaining good plate alignment and fit. Washers of appropriate height can also prevent plate impingement on the adjacent normal facet joints (Fig. 7).

In the authors' early experience, the vertebrae with instrumentation were locked in distraction.[56] It was suspected that distraction placed a constant unidirectional torque on the screw against one wall of the pedicle, possibly resulting in erosion, migration of the screw, or pedicle fracture (Fig. 8). Pedicle fracture occurred intraoperatively in some osteopenic patients. Distraction at one segment may cause compression of adjacent segments that are included in the construct (Fig. 9), resulting in disc narrowing and foraminal stenosis to the instrumented level above or below.

The use of rod systems, even those without three-dimensional adjustability between the screw and the rod (e.g., Isola), may be less likely to result in screw bending, because the rod can be more easily contoured than a plate. Rod systems with three-dimensional adjustability (e.g., Vermont spinal fixator) virtually eliminate the screw bending problem, because any screw-rod align-

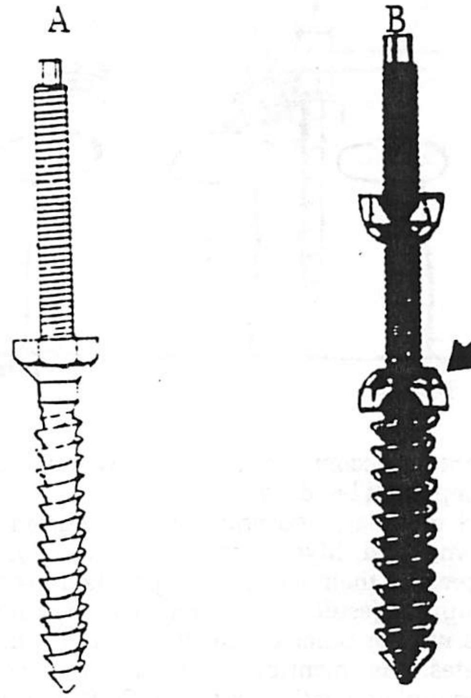


Figure 4. *A*. Standard VSP screw. *B*. Modified pedicle screw with nuts containing spherical upper surfaces to fill the nest on the lower surface of the plate. These may be tightened in different directions. not even perpendicular to the plate.

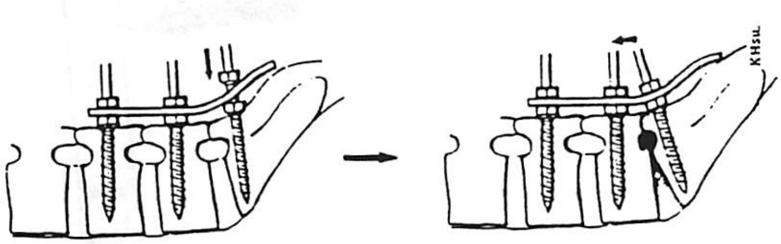


Figure 5. Nuts do not lock until the screw finds a stable position over a sharply curved plate. Foraminal stenosis may be produced by this mechanism.

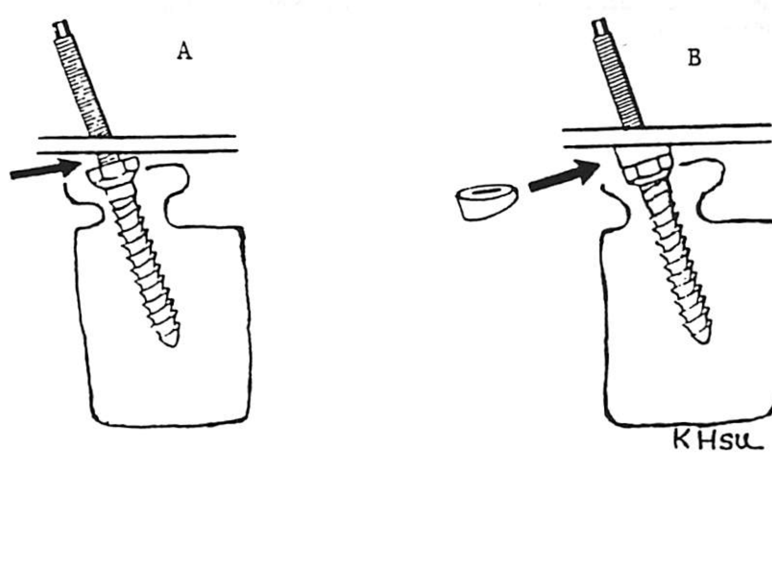


Figure 6. *A*. When the screw is not perpendicular to the plate, eccentric torque stress is generated against the pedicle. Significant bending stress is also generated against the screw when the posterior nut is tightened to the plate. *B*. A wedge-shaped washer improves the fit of the screw nut to the plate and reduces such stresses.

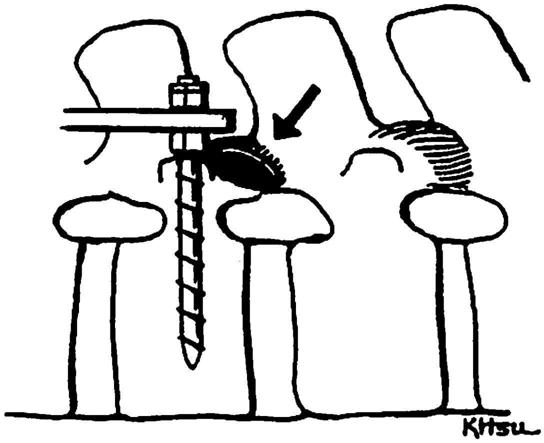


Figure 7. When a screw is inserted into the pedicle, the adiacent tacet is oiten violated.

ment is accommodated even without any component bending.

Screw-plate loosening was reported by Davne and Myers[5] to occur in 5.6% of screws in their series. This problem may be simply a result of inadequate tightening of the nuts or other connectors to the rods or plates. As mentioned previously, secure screw-plate fixation with the Steffee system can be achieved by use of an appropriate washer (angled or straight). Perhaps pedicle fracturing or erosion contributes to screw-plate loosening (by causing increased loading of the screw-plate interface), although it is also possible that fracturing or erosion tends to happen with screws that are malaligned to the plate and not securely attached to the plate initially. For systems in

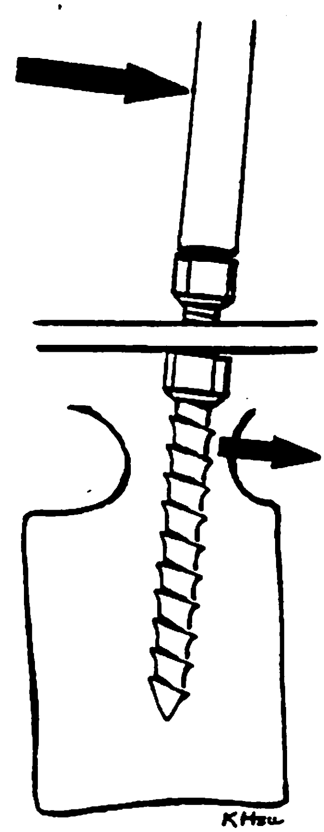


Figure 8. Extreme distraction of the screws results in constant forces unilaterally against the pedicle, which may result in fracture or erosion of the screw through the pedicle.

xation systems were developed and are still evolving and ıve been found to be effective if properly utilized. The :west approach to instrumentation in the lumbar spine has :en an interbody fixation technique using bullet-shaped, threaded, hollow fusion cages. These have been found to old the vertebra as still as the screw and rod versions, and they sit in the interbody space right at the center of motion f the spine. These fusion cages have completed FDA Clinical trials and the early results seem to be favorable and they :e recessed for general use.

bout four years ago, my associates and I at the St. Mary's Spine Center in San Francisco, obtained a research grant in :der to develop a laparoscopic percutaneous fusion procedure. Our original plan was to utilize donor bone augmented ith bone morphogenic protein placed within the disc space to cause the fusion to take.

/e began performing the procedure in pigs in order to develop the approach and instrumentation. Shortly after this, :evelopment of the fusion cages provided an ideal internal fixation device that could be passed through a tube into the isc space, with minimal need for visualization and exposure. Over a couple of years, specific instrumentation for ısertion of the cages laparoscopically was developed in prototype until we were able to perform the procedure reliably ı the porcine model. We performed the first human instrumented laparoscopic spinal fusion in the world in September 993, and since then the procedure has also been performed all over the worlds and FDA will likely soon approve this :chnique for general use. Obviously, it is too soon to give objective data in regard to clinical results. However, our npression is that once the learning curve is mastered, the procedure has significant advantages over other fusion :chniques because of diminished hospitalization, diminished patient discomfort, diminished medical expense, and an xpected high fusion rate. The specifics of the procedure are important here as some levels in the spine are more :chnically difficult to do that others.

here has been a study comparing the medical expense of open and laparoscopic techniques for procedures commonly one in general surgery. Laparoscopic techniques showed significant cost savings. We believe this will be the same :sult in endoscopic spine surgery, especially after the instrumentation, technique, and surgical expertise are further :fined. Advancements in fiber optic visualization and remote instrumentation will certainly broaden the applications for ıe procedure, as our capacity to manipulate tissue through small holes from remote sites safely increases. Thus, less nd less normal tissue will have to be violated in order to correct the areas of abnormality which are much smaller than ıe currently used exposures.

he technique for laparascopic spine fusion surgery , which will be illustrated in the videotape, is basically as follows: ı special insufflation needle is placed through the umbilicus into the peritoneal cavity and air is insufflated into the eritoneum. This creates a space so that the abdominal cavity can be clearly visualized with the laparoscope. A 1 cm ıcision is made and the laparoscope is inserted through a trochar and the abdominal cavity visualized. Under direct isualization, two more 1 cm incisions are made for retractors and operating instruments on either side opposite the :vel to be fused. Under direct, and I must say extremely clear, visualization, dissection is carried out at the bottom of ıe abdominal cavity overlying the spine, to expose the anterior aspect of the discs. An electrical cutting device makes n incision on one side of the disc and alignment is checked with a mobile fluoroscope machine. A 13-17 mm incision is ıade directly over the disc to be operated on, and the operating trochar is placed under visualization into the abdominal avity. Through the incision made in the disc, a series of increasingly larger spacers are used in order to restore the eight of the degenerated disc back to its original size. This distraction force causes compression on the intervertebral pace which will anchor the fusion cage in place and also internally fix the vertebra on either side. After the disc is istracted by the spacers to the desirable height, an incision is made on the other side of the disc and the operating ochar tube placed over the incision anchored in the bone of the vertebra above and below. Reamer drills are then used › drill out the disc material and a portion of the vertebra above and below. A tapping device is used to tap the ıtervertebral space before the fusion cage is placed. The fusion cage is packed with bone taken from the drill reamings r from the anterior or posterior pelvis, at the surgeon's discretion, and screwed into position inside the intervertebral pace. Attention is then directed back to the other side of the disc. The spacer is removed, and in a similar fashion, nother fusion cage is placed on that side. More bone is placed within the fusion cage and this essentially completes the rocedure. The small incisions are closed and the patient is expected to ambulate the day following the procedure. ›ischarge is expected two to four days after the procedure.