Anterior transvertebral interbody cage with posterior transdiscal pedicle screw instrumentation for high-grade spondylolisthesis

Technical note

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Adult high-grade degenerative spondylolisthesis represents the extreme end of the spectrum for spondylolisthesis and is consequently rarely encountered. Surgical management of high-grade spondylolisthesis requires constructs capable of resisting the shear forces at the slipped L5–S1 interspace. The severity of the slip, sacral inclination, and slip angle may make conventional approaches to 360° fusion difficult or hazardous. Transdiscal pedicle screw fixation, transvertebral fibular graft fusion, and transvertebral cage fixation are techniques that have been developed to establish anterior column load sharing and to resist shear forces at the L5–S1 interspace, given the anatomical constraints accompanying high-grade spondylolisthesis. In this technical note the authors describe the procedure for implanting an in situ anterior L5–S1 transvertebral cage and performing L4–5 anterior lumbar interbody fusion, followed by placement of posterior S1–L5 vertebral body transdiscal pedicle screws for management of high-grade spondylolisthesis.

KEY WORDS • spondylolisthesis • transvertebral cage • image-guided surgery

A small subpopulation of adult and pediatric patients with spondylolisthesis will suffer slippage and progression to high-grade spondylolisthesis. The main goals of surgical management for high-grade spondylolisthesis are relief of pain and neurological deficits. This is typically accomplished by decompression and in situ fusion, or occurs following reduction. It is also critical to create a structurally solid three-column construct that will fuse without causing new neurological complications. The surgical management of spondylolisthesis is often complicated by distorted anatomy due to protrusion of L-5 over the sacral promontory, a high degree of sacral inclination, unfavorable slip angle, and loss of normal lordosis (Fig. 1).

Traditional posterolateral fusion with pedicle screw instrumentation for high-grade L5–S1 spondylolisthesis is associated with a high rate of slip progression because the construct does not provide anterior column axial load sharing and it is unable to restrict shear forces across the disc space. To provide anterior column load sharing and a larger surface area for fusion, ALIF is frequently used in addition to posterolateral fusion. This significantly improves the rate of fusion and reduces slip progression, but adds the risk, increased operating time, and morbidity associated with an anterior procedure. Furthermore, interbody grafting for a high-grade L5–S1 spondylolisthesis can be of marginal efficacy because of the limited end-plate surface area available to create an interface with a graft when the L-5 VB has slipped more than 50% over the sacral promontory.

The severity of slippage, sacral inclination, and slip angle can affect the relationship of the L5–S1 disc space to the symphysis pubis and make a straight anterior trajectory to the lumbosacral interspace for a normal anterior lumbar interbody approach impossible. A variety of techniques have been described to improve successful arthrodesis in this setting, including transdiscal pedicle screw fixation, anterior or posterior transvertebral fibular graft fusion, and posterior transvertebral cage fixation. Our technique for management of high-grade spondylolisthesis involves in situ placement of an anterior L5–S1 transvertebral cage and L4–5 ALIF, followed by insertion of S1–L5 VB transdiscal screws and posterior L4–S1 instrumentation attached to pedicle screws placed at these levels. In this article we discuss preoperative considerations, our surgical technique, and other management strategies for high-grade spondylolisthesis.
Preoperative Considerations

Candidate selection requires a thorough assessment of the risks and realistic expectations of in situ anterior and posterior fusion based on the patient’s symptoms, radiographic findings, and medical comorbidities. Preoperative sagittal MR imaging is helpful in assessing the degree of central canal and neuroforaminal stenosis as well as the degree of disc degeneration. The severity of the patient’s spondylolisthesis may be seen more readily on standing lateral radiographs than is demonstrated with the candidate in the supine position on CT and MR imaging studies (Fig. 2).

The combined effect of high-grade slippage, marked sacral inclination, and an unfavorable slip angle can affect the L5–S1 disc space in relation to the symphysis pubis, so that a straight trajectory to the lumbosacral interspace is impossible. This would disqualify conventional ALIF at the L5–S1 levels. Under similar circumstances, however, transvertebral cage placement is usually possible. The cage length, diameter, and trajectory should be optimized to establish the maximum bone surface area between L-5 and the sacrum and to provide enough structural resistance to the axial and shear forces acting at the L5–S1 interbody disc space. For this reason, we usually use a 12-mm-diameter cage. Review of preoperative sagittal CT scans helps with this planning.

Surgical Technique

The patient is placed supine on a radiolucent Jackson table. A combination of propofol and remifentanil is used for sedation and analgesia to allow neuromonitoring. Electrodes are placed to allow electromyography to be performed and somatosensory evoked potentials to be tested throughout the operation.

After the abdomen is prepared and draped in a sterile fashion, a general or vascular surgeon performs an anterior retroperitoneal exposure of the L4–5 disc space and a caudal exposure over the anterior surface of the L-5 VB. With the aid of lateral fluoroscopic guidance, a K-wire is advanced obliquely from approximately 5 mm below the anterosuperior L-5 endplate along a midline sagittal trajectory through the body of L-5, across the midpoint of the overlapping endplates and disc space between L-5 and S-1, and into the body of the sacrum. The wire should be advanced with great care to avoid breach of the posterior cortex adjacent to the sacral spinal canal.

Starting with the 7-mm size, sequential reamers are passed over the K-wire until an 11-mm reamed canal is established from the anterosuperior portion of the L-5 VB through the disc space and into the sacral body. All bone dislodged during reaming is saved to be packed in the mesh cage as autograft. After proper sizing of the reamed canal, an appropriately fitted (45–60 mm × 12 mm) mesh cage is driven into the prepared area, using a 9-mm reamer for guidance. The cage is then packed with autograft and recombinant human bone morphogenetic protein–2 (INFUSE Bone Graft; Medtronic Sofamor Danek, Memphis, TN).

Once the cage is placed in situ, a standard L4–5 ALIF procedure is performed. The construct’s position is confirmed with AP and lateral fluoroscopic imaging and the anterior exposure is closed by the general surgeon.

The patient is then placed prone by rotating the radiolucent Jackson table 180°. After the patient is prepared and draped in a sterile fashion, a midline linear incision is made over the lumbosacral junction. The paraspinal muscles are dissected laterally off the L-4, L-5, and sacral posterior elements to the transverse processes in a subperiosteal manner.

Image guidance is used for placement of posterior instrumentation. With a reference array attached to the spinous process of L-3, the ISO-C 3D system (Siemens Medical Solutions, Erlangen, Germany) is used to acquire 100 isocentric fluoroscopic images automatically; these are reformatted into a 3D data set. The 3D data set is then transferred to the Stealth TREON unit (Medtronic, Louisville, CO) for navigation.

Using an image-guided awl/probe/tap instrument, L-4 pedicle screws are placed with the screw heads left protruding above the facet joints to accommodate the significant offset between L-4 and sacral pedicles. Attention is then directed to the more difficult-to-place transdiscal screws fixing the S-1 pedicle to the L-5 VB. Image guidance is used to select an optimal entry point and trajec-
The patient underwent anterior in situ L5–S1 transverse process fusion, L4–S1 ALIF followed by securing of the posterior S-1 pedicle to the L-5 VB with transdiscal screws that were then connected with a rod to L-4 pedicle screws, Gill decompression of the L-5 posterior elements, and posterolateral fusion from L-4 to the sacrum. There were no surgical complications.

**Postoperative Course.** The patient did well throughout his hospitalization and had no complications. He was walking with the support of a lumbosacral brace and tolerating his diet on postoperative Day 1. He continued to work with a physical therapist until postoperative Day 3, when he was discharged. He had discontinued all analgesic medications and was walking 30 minutes twice a day by the 2nd postoperative month.

**Discussion**

**Posterolateral Fusion**

Lenke, et al., 16 found a pseudarthrosis rate of 36% in 14 pediatric patients with high-grade L5–S1 spondylolisthesis who were treated with in situ bilateral transverse process fusions to the sacral ala without instrumentation. Overall, in situ posterolateral fusion with pedicle screw instrumentation for high-grade L5–S1 spondylolisthesis has a reported pseudarthrosis rate of 17 to 40%.6,8,15 The tendency of this type of fusion to fail is multifactorial. First, instrumented posterolateral fusion without anterior axial load sharing makes axial compressive forces transmit through the pedicle screws via the posterior rods.17 The flexibility of the rod and screw construct results in bending micromotion that increases the likelihood of hardware failure and inhibits fusion. Second, an instrumented posterolateral fusion construct is mechanically disadvantaged for restricting the strong shear forces at the L5–S1 interspace in patients with high-grade spondylolisthesis. Third, the deep-seated L-5 transverse process is often small or dysplastic, which leaves less bone surface area at L-5 for fusion to the sacral ala.11,21

Ani, et al., 2 presented a series of 20 patients with high-grade spondylolisthesis who were treated with instrumented posterolateral fusion. Seventeen of these patients were treated with reduction, interbody arthrodesis, and posterolateral fusion with pedicle screw instrumentation. None of the

**Illustrative Case**

**History and Examination.** This 34-year-old man presented with a 2-year history of progressive back pain and bilateral radicular symptoms in the L-5 distribution. His back pain was worse when he engaged in standing activities but disappeared almost completely when he lay supine. A 1.5-year regimen of conservative management, including chiropractic manipulation, physical therapy, and orally administered analgesic medications failed to relieve his pain, and he was unable to work. On physical examination he exhibited diminished pinprick sensation over the dorsum of his right foot but was otherwise neurologically intact.

**Neuroimaging Findings.** Admission MR imaging studies and CT scans demonstrated Grade III spondylolisthesis at L5–S1 as well as bilateral neuroforaminal stenosis (Fig. 3). The discs at the L5–S1 and L4–5 interbody spaces had degenerated, but the lumbar discs above L-4 appeared to be normal on T2-weighted MR imaging. Lateral lumbar x-ray films obtained with the patient standing showed Myerding Grade III–IV spondylolisthesis and an L5–S1 disc space directed downward to the floor.

**Operation.** The patient underwent anterior in situ L5–S1 transverse process fusion, L4–S1 ALIF followed by securing of the posterior S-1 pedicle to the L-5 VB with transdiscal screws that were then connected with a rod to L-4 pedicle screws, Gill decompression of the L-5 posterior elements, and posterolateral fusion from L-4 to the sacrum. There were no surgical complications.

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the 17 patients lost their reduction. The three remaining patients were initially treated with reduction and instrumented posterolateral fusion without interbody arthrodesis. All three experienced progression of slippage and underwent staged interbody fusion after slip progression was noted on follow-up evaluations. Ani and coauthors concluded that interbody fusion provides essential anterior column support and load sharing necessary for construct stability. Many authors have advocated combined anterior and posterior arthrodesis in high-grade spondylolisthesis.

Anterior Column Support and Resistance to Shear Forces

Several approaches have evolved to provide structural support to the anterior column in high-grade spondylolisthesis. In 1994 Abdu, et al., described sacral pedicle screws inserted via a posterior approach to cross the disc space into the VB of L-5. This technique provides anterior column support, a large, multicortical surface area of bone for screw fixation, and instrumentation to resist shear forces across the disc space while posterolateral fusion is occurring. It also avoids the technical difficulties of inserting screws into the pedicles of the slipped L-5 vertebra. The strength of this construct is attributed to the purchase gained by the long triangulated screws on the cortical endplate near the sacral promontory and the L-5 inferior endplate. In cadaveric models of moderate-grade spondylolisthesis, transdiscal L5–S1 screw fixation produced constructs that were 1.6 to 1.8 times stiffer than traditional pedicle screw fixation. Furthermore, the stiffness of the transdiscal fixation was equal to that of a combined interbody fusion with pedicle screw fixation.

For patients with high-grade spondylolisthesis and high slip angles, transvertebral interbody fibular dowels can be inserted through a reamed canal via anterior or posterior approaches to provide anterior column support and resistance to shear forces across the L5–S1 disc space. The intention in using the fibular dowel is that it will act as a pin between the VBs to resist shear forces across the slipped disc space and provide grafting material for subsequent fusion. Roca, et al., reported their results in 14 patients treated with single-stage posterior fibular allograft and posterolateral fusion from L-4 to the sacrum. In one of these 14 patients the fibular allograft fractured, and in another it was resorbed.

Smith, et al., also reported on two of nine patients in whom fibular allograft strut fractures and pseudarthrosis developed after intraoperative distraction reduction followed by posterior transvertebral fibular allograft strut placement. The seven patients in that series who did not suffer strut graft fractures had also received posterior S1–L5 transdiscal pedicle screws connected by rods to L-4 pedicle screws, and they underwent posterolateral fusion. The two patients with pseudarthrosis due to fibular graft fractures underwent revision surgery with S1–L5 transdiscal pedicle screws connected with rods to L-4 pedicle screws and followed by posterolateral fusion. Ultimately, all nine patients attained solid fusions. Smith and coauthors recommended transdiscal pedicle screw instrumentation from the S-1 pedicle to the L-5 VB in patients with high-grade spondylolisthesis treated with reduction and posterior transvertebral fibular allograft strut fixation.

Posterior transvertebral interbody fusion in which an autograft-filled 7-mm cage was used was described by Bartolozzi and coauthors in 2003. In all 15 of the patients in their series, stable fusion was established. An autograft-filled titanium mesh cage immediately provides structural stability in the anterior column, with a higher elasticity modulus to resist shear forces across the L5–S1 disc space, in contrast with fibular autograft or allograft. The titanium cage will not be resorbed, as is the case with fibular allograft, and the autograft within it will enable an interbody fusion to occur. The cylindrical shape of the cage allows for precise reaming and fit of the device. We prefer the largest cage that will fit to provide the most resistance to the shear force. The resistance to shear force increases with...
Anterior transvertebral cage with posterior pedicle screws

the radius squared. Thus, a 12-mm cage is nearly twice as resistant to shear forces as a 7-mm cage.

In Situ Fusion

The patients in our case series underwent in situ fusion during the anterior portion of the operation. There are many factors that support this approach. Preoperatively, these patients’ pain was relieved in the supine position. In addition, supine positioning partially reduced their spondylolisthesis and opened the L5–S1 neural foramina. Finally, L-5 laminectomy and L5–S1 foraminotomy further decompressed the neural elements at the lumbosacral junction. These findings are consistent with those reported by Smith and Bohlman25 in their long-term follow-up study of 11 patients in whom high-grade spondylolisthesis caused severe neurological deficits. None of their patients experienced neurological complications, and all had major or complete neurological recovery with solid fusions after single-stage posterior sacral dome decompression and in situ fusion with fibular strut autograft. Based on their findings, these authors recommended decompression when compressive abnormalities were documented, and believed that complications caused by decompression were prevented by in situ fusion.

Intraoperative reduction and instrumentation of L5–S1 high-grade spondylolisthesis is associated with an 8 to 30% rate of postoperative neurological compromise, mostly consisting of nerve root injuries or cauda equina syndrome.26,27 Somatosensory evoked potentials and the wake-up test have been used to detect intraoperative neurological compromise during reduction of high-grade spondylolisthesis.2,3,21 Molini, et al.,21 found no postoperative neurological deficits in 11 patients who underwent in situ fusion to treat high-grade spondylolisthesis. However, they did find postoperative neurological deficits in four of 26 patients who underwent reduction.

The advantages of reduction are said to include the restoration of the normal alignment of the spine. It is theorized that this restoration of sagittal plane balance may be more effective in treating mechanical back pain, and may also prevent accelerated degeneration from occurring more rostrally. These theories are not well proven. Conversely, the relatively high incidence of well-documented complications associated with reduction, including instrumentation failure, loss of reduction, pseudarthrosis, and neurological deficit would seem to overshadow any subtle theoretical advantages.

Given these arguments and findings, we believe that the risks of reduction in the setting of high-grade spondylolisthesis outweigh the benefits. Thus, our patients are treated with fusion in situ in the supine position.

Image guidance

Imaging guidance is a useful adjunct facilitating the safe and accurate placement of instrumentation. Reconstructed multiplanar images provide the surgeon with a better appreciation of the markedly distorted anatomy associated with high-grade spondylolisthesis. They also allow the surgeon to select an optimal trajectory for instrumentation, and to ensure that it is placed along the intended path (Fig. 4).

There are potential pitfalls when using image guidance based on preoperative data sets, especially in the setting of high-grade spondylolisthesis. Preoperative imaging often misrepresents the patient’s spinal anatomy compared with its intraoperative appearance. Imaging data acquired before surgery do not account for interssegmental vertebral motion associated with intraoperative positioning, surgical decompression, deformity reduction, and placement of instrumentation. For these reasons, surgical navigation based on preoperative images and using point-to-point registration would not have been safe or efficacious.

In our patients, the relationship of the in situ transvertebral cage placed during the anterior portion of the surgery to the surrounding sacral and L-5 VB anatomy needed to be assessed intraoperatively to ensure accurate placement of posterior transdiscal pedicle screws from S-1 to L-5. Intraoperative AP and lateral fluoroscopy can be used for real-time guidance of pedicle screw trajectories in complex spine cases. Unfortunately, in high-grade spondylolisthesis the AP image of the L-5 VB slips anteroinferiorly to the sacrum, and the surrounding pelvic bone anatomy on AP and lateral fluoroscopy makes interpretation of intraoperative images difficult.

Several authors have advocated the adoption of detailed real-time intraoperative imaging in which the ISO-C 3D C-arm navigation system is used in conjunction with an image-guidance navigation platform for planning trajectories and accurate placement of pedicle screws in complex spine cases.13,19,28 Image guidance for transdiscal pedicle screws connecting S-1 to L-5 has not been described. The ability to acquire and view multiplanar 3D images of intraoperative anatomy and simultaneously to register these images with the Stealth TREON unit (Medtronic) for navigation enabled efficient, accurate placement of transdiscal pedicle screws from S-1 to L-5 without abutting the transvertebral cage or breaking out of the L-5 VB.

Villavicencio, et al.,28 reported a remarkably low pedicle screw misplacement rate of 1.5% when using the ISO-C for image set acquisition and Stealth TREON registration. Furthermore, Wang and coauthors29 demonstrated the reliability of ISO-C 3D fluoroscopy for detecting pedicle screw violations in the thoracic and lumbar spine by using a cadaveric model to compare postprocedure ISO-C results with conventional CT studies. We always acquire and review final postfixation ISO-C and postoperative CT scans to confirm accurate placement of instrumentation in patients with high-grade spondylolisthesis (Fig. 5).

Conclusions

Whereas traditional instrumented posterolateral fusion has proven to be reasonably effective in the treatment of high-grade spondylolisthesis, interbody arthrodesis significantly improves surgical outcomes. Several innovative approaches have evolved to address interbody arthrodesis of high-grade L5–S1 slippage given the anatomical constraints that make conventional anterior approaches to the interspace difficult or impossible. The placement of an anterior L5–S1 transvertebral cage, L4–5 ALIF, and posterior L4–S1 pedicle screw fixation with S1–L5 transdiscal pedicle screws successfully accomplishes an in situ fusion. This procedure, in conjunction with an aggressive posteri-
or decompression, has been performed with excellent clinical results and without neurological complications.

Disclosure

Drs. Potts and Mobasser are consultants and instructors for Medtronic Sofamor Danek, and Dr. Karahalios is a consultant for this company. However, no grants or outside funding were supplied in support of this work.

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