Minimally Invasive Multilevel Percutaneous Correction and Fusion for Adult Lumbar Degenerative Scoliosis

A Technique and Feasibility Study

Neel Anand, MD, Eli M. Baron, MD, Gowriharan Thaiyananthan, MD, Kunwar Khalsa, BS, and Theodore B. Goldstein, MD

Study Design: Prospective evaluation of 12 patients undergoing surgery for lumbar degenerative scoliosis.

Objective: To assess the feasibility of minimally invasive spine surgery (MIS) techniques in the correction of lumbar degenerative deformity.

Summary of Background Data: Patient age, comorbidities, and blood loss may be limiting factors when considering surgical correction of lumbar degenerative scoliosis. MIS may allow for significantly less blood loss and tissue disruption than open surgery.

Methods: Twelve patients underwent circumferential fusion. The age range of these patients was 50 to 85 years (mean of 72.8 y). Of the 12 patients, 7 were men and 5 were women. All patients underwent direct lateral transpsoas approach for discectomy and fusion with polyetheretherketone cage and rh-BMP2. All fusions to the sacrum included L5-S1 fusion with the Trans1 Axial Lumbar Interbody Fusion technique. Posteriorly, multilevel percutaneous screws were inserted using the CD Horizon Longitude system. Radiographs, visual analog scores (VAS), and treatment intensity scores (TIS) were assessed preoperatively and at last postoperative visit. Operative times and estimated blood loss were recorded.

Results: Mean number of segments operated on was 3.64 (range: 2 to 8 segments). Mean blood loss for anterior procedures (transpsoas discectomy/fusion and in some cases L5-S1 interbody fusion) was 163.89 mL (SD 105.41) and for posterior percutaneous pedicle screw fixation (and in some cases L5-S1 interbody fusion) was 93.33 mL (SD 101.43). Mean surgical time for anterior procedures was 4.01 hours (SD 1.88) and for posterior procedures was 3.99 hours (SD 1.19). Mean Cobb angle preoperatively was 18.93 degrees (SD 10.48) and postoperatively was 6.19 degrees (SD 7.20). Mean preoperative VAS score was 7.1; mean preoperative TIS score was 56.0. At mean follow-up of 75.5 days, mean VAS was 4.8; TIS was 28.0.

Conclusions: A combination of 3 MIS techniques allows for correction of lumbar degenerative scoliosis. Multisegment correction can be performed with less blood loss and morbidity than for open correction.

Key Words: minimally invasive spine surgery, deformity, lumbar degenerative scoliosis

(*J Spinal Disord Tech* 2008;21:459–467)

Lumbar degenerative scoliosis is a common degenerative condition of the lumbar spine associated with considerable morbidity. Most cases are treated conservatively.[1,2] When surgical correction and fusion is contemplated for symptomatic patients with symptoms refractory to conservative treatment, the combination of patient age, medical comorbidites, and considerable blood loss is a significant limitation in the operative treatment of lumbar degenerative scoliosis. Minimally invasive spine surgery (MIS) may allow for surgery of the lumbar spine with considerably less blood loss and soft tissue damage. Nevertheless, to date, MIS circumferential treatment of multilevel lumbar degenerative scoliosis has not been described. This study describes the technique and looks at the feasibility of performing deformity correction through circumferential multilevel MIS fusion using a combination of 3 novel innovative techniques.

MATERIALS AND METHODS

Patient Population

Twelve consecutive patients who have had minimally invasive percutaneous correction and fusion of adult lumbar degenerative scoliosis were included in the study. All were symptomatic and had failed extensive conservative therapy. Their ages ranged from 50 to 85, with a mean of 72.83 (SD 9.2). There were 7 men and 5 women.

Study Design

Data for this study was obtained through retrospective chart reviews and concurrent follow-up of patients who underwent minimally invasive lumbar interbody fusion without decompression by a single spine surgeon (N.A.) at the Cedars-Sinai Institute for Spinal

Received for publication October 26, 2007; accepted January 5, 2008.
From the Department of Surgery, Institute for Spinal Disorders, Cedars-Sinai Medical Center, Los Angeles, CA.
Reprints: Neel Anand, MD, Institute for Spinal Disorders, Cedars-Sinai Medical Center, 444 S. San Vicente Blvd., Suite 800, Los Angeles, CA 90048 (e-mail: neel.anand@cshs.org).

Disorders in Los Angeles, CA, between 2006 and 2007. Outcome data were obtained prospectively preoperatively and at each visit postoperative through self-administered questionnaires.

Technique

The patients presented in this study underwent 1 or a combination of the following interbody disc release and fusion procedures: (1) XLIF (Extreme Lateral Interbody Fusion, NuVasive, Inc, San Diego, CA), (2) DLIF (Direct Lateral Interbody Fusion, Medtronic Sofamor Danek, Memphis, TN), (3) Axial Lumbar Interbody Fusion (AxiaLIF) (Trans1, Wilmington, NC). All patients then underwent posterior multilevel percutaneous pedicle instrumentation using the Medtronic CD Horizon Longitude system. If 3 or more levels were being treated, the surgery was staged with the interbody procedures performed at the first stage followed by the posterior instrumentation 2 to 3 days later. The procedures were performed after informed consent was obtained under general anesthesia.

The general techniques of lateral lumbar interbody fusion procedures (XLIF and DLIF) have been described elsewhere[3–8] (Fig. 1). The technique was very similar with both the XLIF and DLIF procedures except for access to the disc space. Propriety instruments were used to gain access to the disc space with the patient in the lateral decubitus position. Propriety neurophysiologic monitoring, including triggered electromyographic response, was used at all times based on the technology used. In degenerative scoliosis, the side selected for access to the disc space was dictated by the ease of access to the L4-5 disc space. If L4-5 was not being fused then access was obtained from the convex side. Careful attention was paid to releasing the disc and annulus all the way to the opposite side so as to get maximal coronal correction at that segment. After appropriate end plate preparation, Lordotic polyetheretherketone spacers augmented with local bone, RhBMP2 ACS (Infuse, Medtronic Sofamor Danek, Memphis, TN) and Grafton Putty DBM was then used to maintain the correction and obtain fusion. The lowest level was always treated first with sequential segmental correction of the segmental deformity obtained. L4-5 was always performed through a separate incision with a separate single incision shared by 2 or more other levels.

The AxiaLIF (Trans1, Wilmington, NC) was used as the percutaneous interbody fusion technique for L5-S1, as the lateral lumbar interbody fusion procedures cannot be performed at L5-S1. The general technique for this approach has also been described in detail elsewhere.[6] We placed the AxiaLIF screw across the L5-S1 disc space with minimal-to-no distraction and relied on the lordotic position and disc release to obtain lordosis. Fusion was obtained with local bone, Vitoss (Orthovita, Malvern, PA) and Grafton putty (Osteotech, Eatontown, NJ) (Fig. 2).

Posterior multilevel percutaneous pedicle screw stabilization was obtained through a novel-free hand technique using the Medtronic CD Horizon Longitude system. The screws were placed percutaneously using fluoroscopic guidance. The cannulated screws, which were inserted over a guide wire, had extenders attached to them, which had a slot to receive the rod. The slot was large enough in the unreduced position to accept a rod that was passed again percutaneous. The rod is contoured according to the sagittal contour desired and then passed free hand through the slots under direct fluoroscopic control. Once the rod is appropriately positioned through all the screw extender slots, the extender is reduced to seat the rod into the tulip of the screw head. Once reduced, the top locking nut is inserted to fix the rod to the screw starting from the caudal screw and working proximally in sequential fashion (Figs. 3, 4). Once all the nuts are in

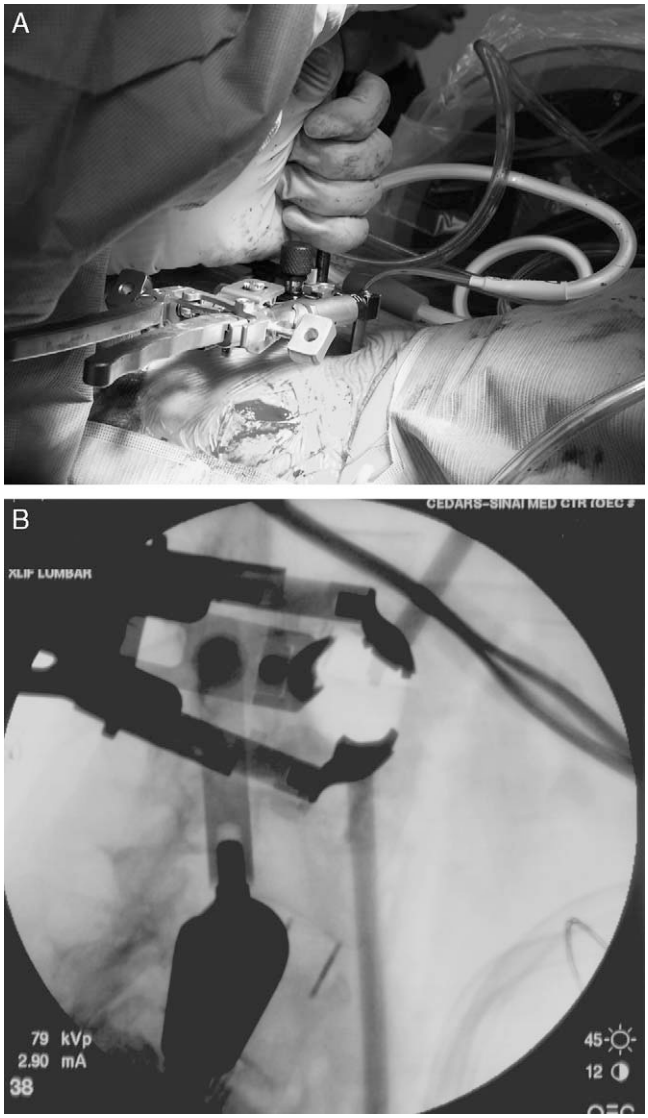

FIGURE 1. A, Intraoperative photo of XLIF being performed. Note the lighted self-retaining MaxAcess retractor. B, Fluoroscopic lateral view of same image. Note the XLIF spacers in place.

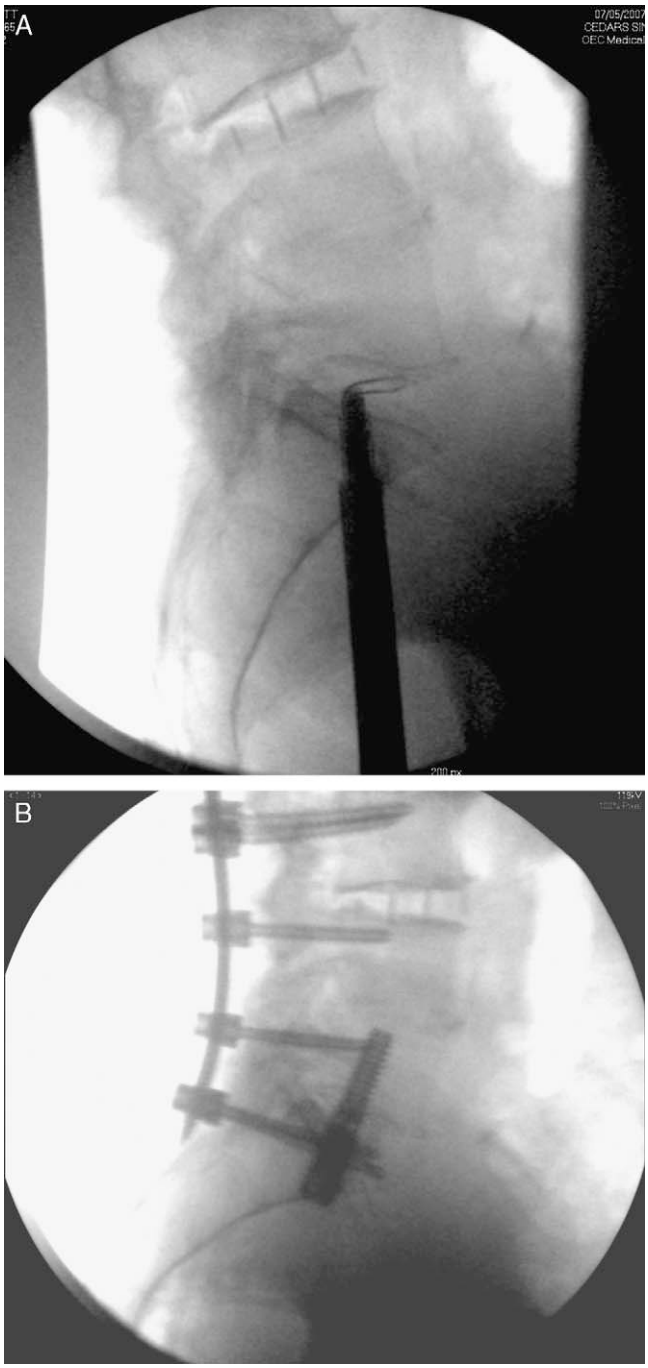

FIGURE 2. A and B, Lateral fluoroscopic images showing (A) Radical discectomy being performed via transsacral approach with nitinol loop cutter (B) Trans1 AxialLIF screw in position at bottom of the construct.

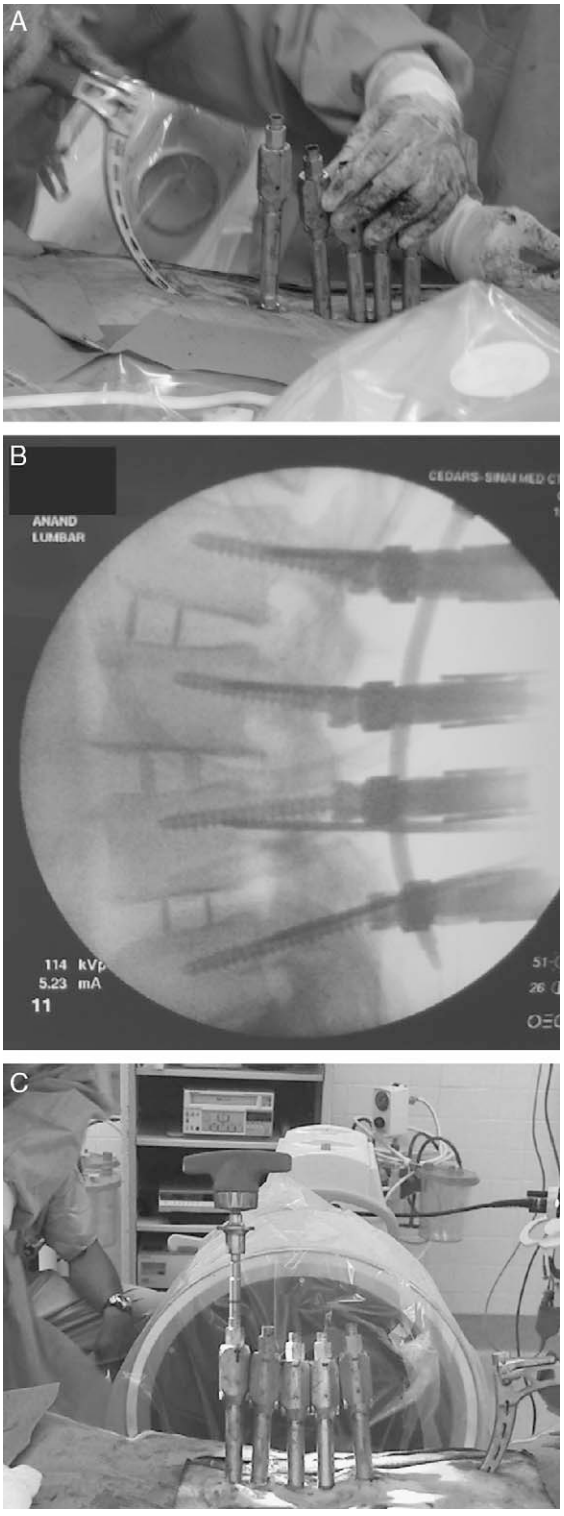

FIGURE 3. A and B, Intraoperative photograph and lateral fluoroscopic image of Medtronic CD Horizon Longitude MIS pedicle screw system with extenders in place with rod being passed through system. C, Once rod is passed, each screw is tested to ensure the rod is actually engaged in the screw head/extender. The line on the device indicates the rod to be engaged.

place, the extender is unseated and detached from the screw. Compression or distraction can be applied to the extenders as desired, to gain further correction as desired (Fig. 5). Posterior fusion was then performed in long fusions at levels that were not fused anteriorly. This was carried out through the same incision used for placing the screws by identifying the facet joints, which were then

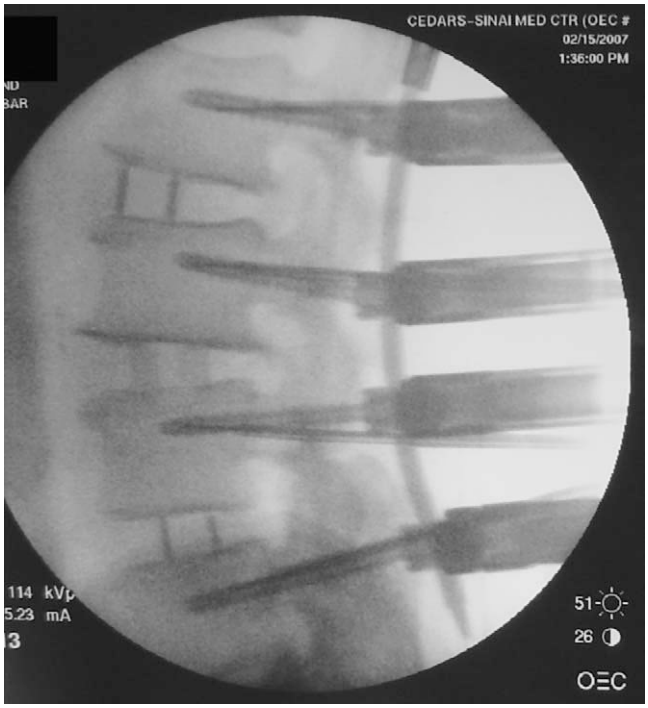

FIGURE 4. Lateral fluoroscopic image of rod reduced.

decorticated with a high-speed drill and grafted with local bone augmented with Grafton putty. In patients where all levels already had anterior lumbar fusion, the pedicle screw instrumentation used a posterior tension band for additional stability and correction.

Study Measures

A research associate at Cedars-Sinai identified individuals who had XLIF, DLIF, and Trans1 procedures with percutaneous screw stabilization, through a review of the database of the surgical cases performed by the senior surgeon. Study measures were obtained through review of patients' clinic charts, operative reports, and inpatient medical records. Surgical outcome data were collected prospectively through regularly scheduled follow-up appointments. The primary measures of this study were blood loss, length of surgery, postoperative hospital stay, and preoperative and postoperative visual analog score (VAS) and the Treatment Intensity Score (TIS). Additionally preoperative and postoperative Cobb angles were measured on 36 degrees standing radiographs.

RESULTS

Twelve patients underwent surgery. Demographics and procedures are shown in Table 1. The mean number of levels operated on was 3.5, with a minimum of 2 levels and a maximum of 8 levels (SD 2.1).

Operative data including estimated blood loss and surgical times are shown in Table 2. The mean blood loss overall for anterior procedures (transpsoas discectomy/fusion and in some cases trans1 L5-S1 interbody fusion) was noted to be 171.9 mL (SD 109.7) and for posterior percutaneous pedicle screw fixation was noted to be 92.5 mL (SD 108.4). The mean surgical time for anterior procedures was noted to be 4.3 hours (SD 2.0) and for posterior percutaneous pedicle screw fixation was noted to be 3.9 hours (SD 1.3). There were no intensive care unit admissions. Mean length of hospital stay was 8.6 days (SD 4.3).

Clinical results including VAS and TIS scores are noted in Table 3. Mean Cobb angle preoperatively was 18.93 degrees (SD 10.48) and postoperatively was 6.19 degrees (SD 7.20).

Complications

There have been no technical issues with the surgical procedures and no surgical complications. Three patients have had thigh dysathesias postoperatively that resolved in 6 weeks. Hip flexor weakness and pain is again not uncommon in the immediate postoperative period on the side through which the transpsoas approach was performed. This usually resolves within 2 weeks. Transient quadriceps weakness was also noted in 1 patient who had L4-5 interbody fusion, which resolved completely in 6 weeks. None of the patients required blood transfusion or admission to the ICU.

DISCUSSION

Lumbar degenerative scoliosis typically occurs in patients older than 60 years of age primarily as a result of degenerative disc disease.[9] Most commonly, patients with lumbar degenerative scoliosis present to the clinician complaining of pain.[1,10,11] Numerous causes of the pain related to lumbar degenerative scoliosis have been identified, including muscular discomfort, facet joint disease, disc degeneration, and/or radiculopathy.[1,9,10,12] Patients frequently complain of pain on convexity of their lumbar curve.[1,10,13] Often the pain worsens throughout the day and worsens with standing or exertion.[1] Radiculopathy maybe present on the side of concavity secondary to pedicle-on-pedicle compression, but may also arise on the convex side because of excessive traction on the nerve root.[1,9,12,14] Nevertheless, unilateral radicular symptoms are much more common on the side of the concavity of the deformity.[2]

Nonoperative management is the mainstay of treatment for lumbar degenerative scoliosis, although evidence supporting it in the literature is sparse.[2] Nonoperative regimens for the management of lumbar degenerative scoliosis include physical therapy, medical treatment of osteoporosis, anti-inflammatory medications, and neuromodulating drugs such as tricyclic antidepressants and gabapentin.[1,2] Spinal orthosis may be useful in some patients to control the symptoms. Nevertheless, the use of a brace is limited by the fact that in many patients it may be ineffective, and there is potential for trunk muscle deconditioning.[1,2] Alternative treatments have been proposed, including acupuncture, chiropractic, yoga, epidural steroids, facet blocks, nerve

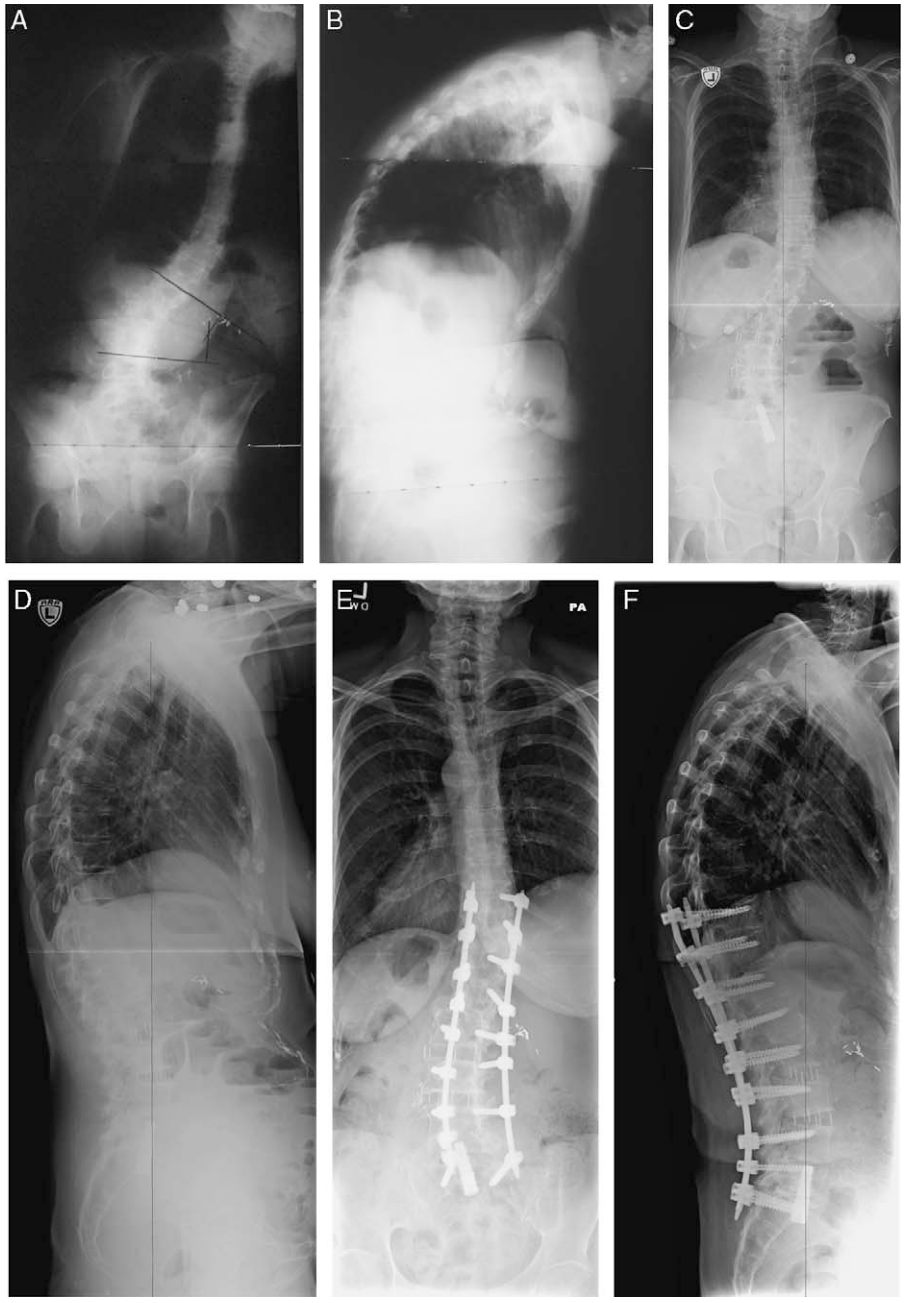

FIGURE 5. A and B, Preoperative anteroposterior and lateral 36 inch films of a 73-year-old woman complaining of severe back pain along her concavity and the inability to stand straight. Despite conservative measures, her symptoms remained severe. Preoperative Cobb angle measured 35 degrees. C and D, AP and lateral postoperative films multisegment XLIF's and Trans1 AxiaLIF. E and F, Final postoperative AP and lateral postoperative films postpedicle screw placement. Compression was performed intraoperatively along the convexity. Postoperative Cobb measured 4 degrees.

root blocks, and trigger point injections. There is minimal data on the efficacy of these in the treatment of lumbar degenerative scoliosis.[2]

A small minority of the patients with lumbar degenerative scoliosis may benefit from the surgery. Relative indications proposed for surgery include curve progression and sagittal and/or coronal imbalance with unremitting back pain, curve flexibility of $> 50\%$ when decompression is being considered, documented history of progressive curve, radiculopathy on the side of the concavity of the curve (as a result of pedicle-on-pedicle stenosis), loss of lumbar lordosis in patients with a history of flat back syndrome/back pain, a fixed lateral listhesis within the degenerative curve where motion is present on side bending film, and if extensive decompression, including facetectomy or parsectomy, is planned.[14]

TABLE 1. Patient Demographics and Procedures

Age	Diagnosis	Surgery Type/Spinal Levels
72	Degenerative scoliosis	T12-L1, L1-2, L2-3, L3-4, L4-5 anterior lumbar interbody fusion (XLIF), L5-S1 anterior lumbar interbody fusion (Trans1), posterior T12- S1 fusion
75	Degenerative scoliosis, degenerative disk disease	L1-2, L2-3, L3-4, L4-5 anterior lumbar interbody fusion (XLIF), L5-s1anterior lumbar interbody fusion (Trans1), posterior L1-S1 fusion
80	Degenerative scoliosis, degenerative disk disease	L2-3, L3-4 anterior lumbar interbody fusion (XLIF) using BMP, L2-4 posterior instrumentation and fusion
85	Degenerative disk disease, stenosis	L2-3, L3-4, lateral interbody fusion (DLIF) using PEEK and BMP, L2-4 posterior instrumentation
75	Degenerative scoliosis, degenerative disk disease	L1-2, L2-3, L3-4 anterior lumbar interbody fusion (XLIF) using PEEK and BMP, L1-2, L2-3, L3-4 posterior instrumentation and fusion
66	Degenerative disk disease, stenosis, radiculitis	L2-3, L3-4 anterior interbody fusion (DLIF) w/ PEEK and BMP, L2-5 posterior instrumentation and fusion, L2,3,4,5 bilateral microdecompression
66	Degenerative scoliosis	L2-3, L3-4, L4-5 anterior lumbar interbody fusion (XLIF) with PEEK and BMP, L2-5 posterior instrumentation and fusion, L2, 3, 4 lateral microdecompression
74	Degenerative disk disease, degenerative scoliosis	L2-3, L3-4 anterior lumbar interbody fusion (XLIF) using PEEK and BMP, L2-4 posterior instrumentation and fusion
50	Degenerative disk disease, degenerative scoliosis	L2-3, L3-4 anterior lumbar interbody fusion (DLIF) using PEEK and BMP, L2-4 posterior instrumentation and fusion
74	Degenerative scoliosis	L2-3, L3-4, L4-5 lateral interbody fusion (XLIF) using PEEK and BMP, anterior lumbar interbody fusion, Trans 1 AxiaLIF, T10-sacrum posterior instrumentation and fusion
83	Degenerative scoliosis	L1-2, L2-3. L3-4 lateral interbody fusion (XLIF), using PEEK and BMP, anterior lumbar interbody fusion, Trans 1 AxiaLIF, posterior instrumentation L1-S1
74	Degenerative scoliosis	L2-3. L3-4 lateral interbody fusion (XLIF), using PEEK and BMP, anterior lumbar interbody fusion, Trans 1 AxiaLIF, L2-S1 posterior spinal instrumentation.

AxiaLIF indicates axial lumbar interbody fusion; BMP, bone morphogenetic protein; DLIF, direct lateral interbody fusion; PEEK, polyetheretherketone; XLIF, extreme lateral interbody fusion.

TABLE 2. Operative Data

	Anterior Procedures	Minimally Invasive Posterior Stabilization and Possible Decompression or Fusion
Estimated blood loss (mL)		
Mean	163.89	93.33
SD	105.41	101.43
Minimum	75.00	5.00
Maximum	350.00	325.00
Operative time (h)		
Mean	4.01	3.99
SD	1.88	1.19
Minimum	2.00	1.50
Maximum	7.50	5.50

If surgery is planned, the goals of surgical intervention should include addressing radicular symptoms, halting deformity progression, restoring sagittal balance, and restoration of function.[1] Nevertheless, given the age and medical comorbidities of these patients, surgical management represents a significant challenge. Additionally, elderly patients undergoing surgery for lumbar degenerative scoliosis may be at increased risk of cardiovascular disease, diabetes and obesity.[15] Given that the average blood loss for adult deformity fusion and correction surgery has been reported at 1.5 L, ranging from 360 to 7000 mL for instrumented fusion,[16,17] the case may be made against such operative interventions in elderly patients, given their theoretically increased cardiovascular risk. As a result, consideration for focal short-segment fusions in the presence of adult spinal deformity has been suggested.[18] Nevertheless, this approach may not address the deformity-related issues and there may be an increased possibility of needing an additional procedure.

As far as the extent of fusion is concerned, Suk et al[19] have proposed to extend lumbar fusion routinely to T9 or T10, on the basis of the biomechanical principles and case control data.[20] This approach, however, has the disadvantage of increased operative time and theoretically increased blood loss, which may not be tolerated in the elderly. Additionally, extension to the sacrum may have a high pseudoarthrosis rate and high complication rate.[21,22] Considering that lower pseudoarthrosis rate may be demonstrated by providing anterior column supported L5-S1,[23] the addition of an anterior lumbar interbody fusion, transforaminal lumbar interbody fusion, or posterior lumbar interbody fusion may add considerable amount of operative time and blood loss. This is a problem in the elderly, in addition to the inherent complications and morbidities associated with provision of anterior column support. Finally, osteoporosis may be

TABLE 3. Clinical Outcomes

	Follow-up Time (d)	VAS Preoperative	VAS Postoperative	TIS Preoperative	TIS Posoperative
Mean	75.5	7.1	4.8	56.0	28.0
SD	46.9	2.8	1.9	18.2	19.8
Minimum	15.0	1.0	2.0	28.0	4.0
Maximum	140.0	10.0	7.0	76.0	48.0

TIS indicates treatment intensity scores; VAS, visual analog scores.

a significant contributor to deformity and degenerative scoliosis. This may be a limitation in the treatment of patients over age 65 for lumbar degenerative scoliosis and may be associated with higher instrumentation-related complications.[24]

Given that minimally invasive spinal fusion has been associated with decreased blood loss, decreased hospital stays, and decreased pain in comparison to open fusion,[25] MIS may serve a particularly useful role in the management of lumbar degenerative scoliosis. Though minimally invasive fusion has been associated with good initial results, most series discussing minimally invasive spinal fusion have been in the presence of short-segment fusion.[25–29] To date, there are no reports of circumferential multilevel minimally invasive spinal fusion being performed for lumbar degenerative scoliosis. Additionally, few systems are available that permit multilevel percutaneous pedicle screw fixation, over more than 3 or 4 spinal segments.

Historically, anterior minimally invasive procedures have been associated with a theoretical greater incidence of complications and increased technical difficulties when compared with open approaches.[5] XLIF and DLIF, both minimally invasive direct lateral transpsoas approaches to the lumbar disc space, represent excellent minimally invasive technique for the performance of discectomy and release from L1 to L5. It provides advantages over anterior lumbar interbody fusion, in that anterior lumbar interbody fusion has been associated with several serious complications, including ureteral injuries,[30] vascular injuries,[31,32] bowel injury, and sexual dysfunction.[32] Additionally, XLIF and DLIF provide for ipsilateral and contralateral annulus release and discectomy with placement of a large interbody spacer from 1 side to the other allowing for correction of coronal deformity. It also spares the posterior elements and avoids scarring adjacent to the neural elements by avoiding entry into the spinal canal.[33–35] The transpsoas approach to the lumbar disc space can be associated with potential complications, including hip flexor weakness, lumbosacral plexus nerve injury, genitofemoral nerve injury, and spinal nerve injury. Nevertheless, based on the reported experience in the United States[36] and the experience of Cedars-Sinai,[37] common complications such as weakness of ipsilateral psoas muscle appear transient. Thus, these minimally invasive transpsoas approach allow for the advantages of AxiaLIF over posterior approaches with much less risk of significant vascular or visceral injury. The true incidence of vascular injury with the lateral transpsoas approach is unknown, but its incidence seems much smaller than the often-quoted rate of 6.66% associated with AxiaLIF.[32] The procedure is usually very well tolerated. It is performed through a very small incision with bleeding rarely being encountered. Additionally, a vascular cosurgeon is not needed.

Given the location of the iliac crest relative to the L5-S1 disc space, a transpsoas approach to this disc is not feasible. The trans-1 AxiaLIF system is a novel innovative technique of achieving fusion across the L5-S1 disc space in a minimally invasive manner. Through this approach, the L5-S1 disc is accessed and discectomy is performed while preserving the integrity of muscles ligaments and annulus.[6] Additionally, on a human pilot study there were no observed complications,[38] although theoretically bowel injury or vascular injury is possible. The AxiaLIF transsacral screw system in conjunction with facet screw fixation has been demonstrated to provide significant rotational stability and stiffness, comparable with pedicle screw and rod systems.[39]

The third novel technology that complements the above interbody fusion procedures is multilevel percutaneous pedicle screw fixation, the global MIS reconstruction correction and fusion of the spine in adult scoliosis. This has been made feasible with the Medtronic CD Horizon Longitude System. The longest extent of our fusions performed with this technology has been from T10 to the sacrum. The technical limitations of multilevel posterior pedicle screw fixation via percutaneous techniques that exist with the conventional systems have been overcome via this novel system. Nevertheless, there is a learning curve associated with this as with any new technique. The rod is placed free hand, unlike the Medtronic Sextant system or other systems. Similar to other minimally invasive systems, pedicle screws have extenders. The extenders have a large slot, which accommodate free hand placement of the rod. The ability to contour the rod as required to reestablish the sagittal profile is a significant advantage compared with the conventional systems where one is constrained by a fixed lordotic arc within the rod. This also allows for percutaneous instrumentation of the thoracic and thoracolumbar areas where a fixed lordotic rod is not desirable.

Overall, the degree of deformity correction achieved was excellent. Mean Cobb angle preoperatively was 18.93 degrees (SD 10.48) and postoperatively was 6.19 degrees (SD 7.20). Considering the short hospital stays associated with these fusions for lumbar deformity and reduced blood loss, the benefits of a minimally invasive approach are apparent. Given that significant blood loss can result in significant fluid shifts affecting pulmonary, cardiac, and renal status and is also associated with significant increased risk for disseminated intravascular coagulopathy, and the fact that the blood product may increase the rate of infection after spinal fusion,[16,40–42] procedures with minimal blood loss may result in considerably less patient morbidity. None of the patients went to the intensive care unit postoperatively and all were transferred to the regular spine floor within an hour of surgery. Mean length of hospital stay was 8.6 days (SD 4.3). This should translate into significant cost savings and will be reported in a separate paper. The long-term results, however, remain to be seen. rh-BMP-2 (Medtronic Corporation, Nashville, TN) was used in all cases with Grafton Putty allograft (Osteotech, Eatontown, NJ). Thus, the morbidity of autograft harvest was avoided. Osteoporosis has still not been addressed. Minimally invasive surgery for lumbar deformity may, however, be

combined with vertebral cement augmentation, such as vertebroplasty or kyphoplasty.

Despite all the above, limitations of minimally invasive spinal fusions have been described, including steep learning curves, increased surgical times, and theoretically increased radiation exposure.[5] As a result, Eck et al[5] stated, "There is little evidence to suggest that the minimally invasive approach anterior lumbar interbody fusion is justified considering the increased risk of complications, steep learning curve and longer surgical times." Posterior minimally invasive approaches, according to Eck et al may be justified, however, as the learning curve is considered more moderate.

Our experience has demonstrated otherwise. We have demonstrated MIS approaches for lumbar degenerative scoliosis to be technically feasible, to be able to be accomplished within very reasonable operative times, to be associated with much less blood loss than open procedures (when compared with the literature), and to be associated with short hospital stays. Table 2 details the lengths of surgery and blood loss associated with anterior and posterior minimally invasive spinal fusions for lumbar degenerative scoliosis. It is considerably less than that associated with lumbar spinal fusions.[16,17] Hospital stay was also very short, averaging . We believe the preliminary outcomes, in terms of both VAS and TIS, a measure of patient narcotic use and pain intervention requirements,[26] demonstrate excellent initial results for these procedures.

CONCLUSIONS

Minimally invasive spine technologies may be used for the surgical treatment of lumbar degenerative scoliosis. The transpsoas approach and the percutaneous approach to L5-S1 via a paracoccygeal approach are useful modalities for achieving excellent discectomy and anterior lumbar interbody fusion. Using this approach with newer posterior percutaneous systems, it is possible to achieve multisegment spinal fusion and deformity correction with significantly less blood loss than reported for traditional open spinal fusions. It remains to be seen whether long-term outcomes are as comparable with the traditional procedure.

REFERENCES

1. Daffner SD, Vaccaro AR. Adult degenerative lumbar scoliosis. *Am J Orthop*. 2003;32:77–82; discussion 82.
2. Tribus CB. Degenerative lumbar scoliosis: evaluation and management. *J Am Acad Orthop Surg*. 2003;11:174–183.
3. Anand N, Baron EM. Minimally invasive transpsoas approach to the lumbar spine: extreme lateral interbody fusion (XLIF) and direct lateral interbody fusion (DLIF). In: Bridwell KH, ed. *Operative Spine Surgery*. Philadephia: Lipincott Williams & Wilkins; 2008: In Press.
4. Baron EM, Anand N. Extreme lateral interbody fusion. In: Lewandrowski K, Yeung CA, Spoonamore MJ, et al, eds. *Minimally Invasive Spinal Fusion Techniques*. Armonk: Summit Communications; 2008:161–172.
5. Eck JC, Hodges S, Humphreys SC. Minimally invasive lumbar spinal fusion. *J Am Acad Orthop Surg*. 2007;15:321–329.
6. Marotta N, Cosar M, Pimenta L, et al. A novel minimally invasive presacral approach and instrumentation technique for anterior L5-S1 intervertebral discectomy and fusion: technical description and case presentations. *Neurosurg Focus*. 2006;20:E9.
7. O'Shaughnessy BA, Liu JC, Koski TR, et al. Pseudarthrosis following Adult Spinal Deformity Reconstruction Treated with Minimally-Invasive Direct Lateral Interbody Fusion. AANS/CNS Section on Disorders of the Spine and Peripheral Nerves. *Phoenix*. 2007.
8. Ozgur BM, Aryan HE, Pimenta L, et al. Extreme Lateral Interbody Fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. *Spine*. 2006;6:435–443.
9. Pritchett JW, Bortel DT. Degenerative symptomatic lumbar scoliosis. *Spine*. 1993;18:700–703.
10. Aebi M. Correction of degenerative scoliosis of the lumbar spine. A preliminary report. *Clin Orthop Relat Res*. 1988;232:80–86.
11. Swank S, Lonstein JE, Moe JH, et al. Surgical treatment of adult scoliosis. A review of two hundred and twenty-two cases. *J Bone Joint Surg*. 1981;63:268–287.
12. Grubb SA, Lipscomb HJ, Coonrad RW. Degenerative adult onset scoliosis. *Spine*. 1988;13:241–245.
13. Briard JL, Jegou D, Cauchoix J. Adult lumbar scoliosis. *Spine*. 1979;4:526–532.
14. Herkowitz HN, Sidhu KS. Lumbar spine fusion in the treatment of degenerative conditions: current indications and recommendations. *J Am Acad Orthop Surg*. 1995;3:123–135.
15. Akbarnia BA, Ogilvie JW, Hammerberg KW. Debate: degenerative scoliosis: to operate or not to operate. *Spine*. 2006;31:S195–S201.
16. Hu SS. Blood loss in adult spinal surgery. *Eur Spine J*. 2004;13 (suppl 1):S3–S5.
17. Moller H, Hedlund R. Instrumented and noninstrumented posterolateral fusion in adult spondylolisthesis–a prospective randomized study: part 2. *Spine*. 2000;25:1716–1721.
18. Weidenbaum M. Considerations for focused surgical intervention in the presence of adult spinal deformity. *Spine*. 2006;31:S139–S143.
19. Suk SI, Kim JH, Lee SM. Incidence of proximal adjacent failure in adult lumbar deformity correction. SRS 38th Annual Meeting. Quebec City, Canada, 2003.
20. Shufflebarger H, Suk SI, Mardjetko S. Debate: determining the upper instrumented vertebra in the management of adult degenerative scoliosis: stopping at T10 versus L1. *Spine*. 2006;31:S185–S194.
21. Edwards CC, II, Bridwell KH, Patel A, et al. Thoracolumbar deformity arthrodesis to L5 in adults: the fate of the L5-S1 disc. *Spine*. 2003;28:2122–2131.
22. Emami A, Deviren V, Berven S, et al. Outcome and complications of long fusions to the sacrum in adult spine deformity: Luque-Galveston, combined iliac and sacral screws, and sacral fixation. *Spine*. 2002;27:776–786.
23. Polly DW Jr, Hamill CL, Bridwell KH. Debate: to fuse or not to fuse to the sacrum, the fate of the L5-S1 disc. *Spine*. 2006;31: S179–S184.
24. DeWald CJ, Stanley T. Instrumentation-related complications of multilevel fusions for adult spinal deformity patients over age 65: surgical considerations and treatment options in patients with poor bone quality. *Spine*. 2006;31:S144–S151.
25. Park Y, Ha JW. Comparison of one-level posterior lumbar interbody fusion performed with a minimally invasive approach or a traditional open approach. *Spine*. 2007;32:537–543.
26. Anand N, Hamilton JF, Perri B, et al. Cantilever TLIF with structural allograft and RhBMP2 for correction and maintenance of segmental sagittal lordosis: long-term clinical, radiographic, and functional outcome. *Spine*. 2006;31:E748–E753.
27. Deutsch H, Musacchio MJ Jr. Minimally invasive transforaminal lumbar interbody fusion with unilateral pedicle screw fixation. *Neurosurg Focus*. 2006;20:E10.
28. Jang JS, Lee SH. Minimally invasive transforaminal lumbar interbody fusion with ipsilateral pedicle screw and contralateral facet screw fixation. *J Neurosurg Spine*. 2005;3:218–223.
29. Schwender JD, Holly LT, Rouben DP, et al. Minimally invasive transforaminal lumbar interbody fusion (TLIF): technical feasibility and initial results. *J Spinal Disord Tech*. 2005;18(suppl): S1–S6.

30. Gumbs AA, Shah RV, Yue JJ, et al. The open anterior paramedian retroperitoneal approach for spine procedures. *Arch Surg*. 2005;140: 339–343.
31. Baker JK, Reardon PR, Reardon MJ, et al. Vascular injury in anterior lumbar surgery. *Spine*. 1993;18:2227–2230.
32. Rajaraman V, Vingan R, Roth P, et al. Visceral and vascular complications resulting from anterior lumbar interbody fusion. *J Neurosurg*. 1999;91:60–64.
33. Enker P, Steffee AD. Interbody fusion and instrumentation. *Clin Orthop Relat Res*. 1994;300:90–101.
34. Karim A, Mukherjee D, Ankem M, et al. Augmentation of anterior lumbar interbody fusion with anterior pedicle screw fixation: demonstration of novel constructs and evaluation of biomechanical stability in cadaveric specimens. *Neurosurgery*. 2006;58:522–527; discussion 522–527.
35. Kozak JA, Heilman AE, O'Brien JP. Anterior lumbar fusion options. Technique and graft materials. *Clin Orthop Relat Res*. 1994;300:45-51.
36. Wright N. XLIF- the United States Experience 2003 to 4. International Meeting on Advanced Spinal Techniques Banff Alberta, Canada, 2005.
37. Baron EM, Anand N, Vaccaro AR. Complications of extreme lateral interbody fusion (XLIF). In: Goodrich JA, Volcan I, eds. *Extreme Lateral Interbody Fusion (XLIF)*. St Louis: Quality Medical Publishing; 2008:In press.
38. Cragg A, Carl A, Casteneda F, et al. New percutaneous access method for minimally invasive anterior lumbosacral surgery. *J Spinal Disord Tech*. 2004;17:21–28.
39. Akeson B, Wu C, Mehbod E, et al. Biomechanical evaluation of anterior transacral fixation. *J Spinal Disord Tech*. 2007. Accepted for Publication.
40. Carson JL, Altman DG, Duff A, et al. Risk of bacterial infection associated with allogeneic blood transfusion among patients undergoing hip fracture repair. *Transfusion*. 1999;39: 694–700.
41. Murphy P, Heal JM, Blumberg N. Infection or suspected infection after hip replacement surgery with autologous or homologous blood transfusions. *Transfusion*. 1991;31:212–217.
42. Triulzi DJ, Vanek K, Ryan DH, et al. A clinical and immunologic study of blood transfusion and postoperative bacterial infection in spinal surgery. *Transfusion*. 1992;32:517–524.

