Title

Comparison of lateral lumbar interbody fusion (LLIF) with open versus percutaneous screw fixation for adult degenerative scoliosis

Journal

Journal of Orthopaedics, 15(2)

ISSN

2589-9082

Authors

Attenello, John
Chang, Charles
Lee, Yu-Po
et al.

Publication Date

2018-06-01

DOI

10.1016/j.jor.2018.03.017

Peer reviewed

Journal of Orthopaedics 15 (2018) 486–489

Contents lists available at ScienceDirect

Journal of Orthopaedics

journal homepage: www.elsevier.com/locate/jor

Original Article

Comparison of lateral lumbar interbody fusion (LLIF) with open versus percutaneous screw fixation for adult degenerative scoliosis

John Attenello[b,*], Charles Chang[a], Yu-Po Lee[c], Vinko Zlomislic[a], Steven Robert Garfin[a], Richard Todd Allen[a]

[a] Department of Orthopaedic Surgery, UC San Diego Health System, University of California, San Diego
[b] Department of Orthopaedic Surgery, University of California San Diego School of Medicine, San Diego
[c] Department of Orthopaedic Surgery, UC Irvine Health, University of California, Irvine

ARTICLE INFO

Keywords:
XLIF
LLIF
Minimally invasive
Adult degenerative scoliosis
Percutaneous interbody fusion

ABSTRACT

Study design: Retrospective Review
Objectives: Compare clinical outcomes and radiographic correction of adult degenerative scoliosis (ADS) patients treated with lateral lumbar interbody fusion (LLIF), combined either with percutaneous (no laminectomy) versus open laminectomy/pedicle screw instrumentation.
Methods: Twenty-two ADS patients undergoing combined LLIF and posterior instrumentation were divided into two groups: thirteen patients underwent LLIF with *open* laminectomy and posterior pedicle instrumentation (Group-1, six revision); nine patients underwent LLIF with percutaneous pedicle instrumentation (no decompression) (Group-2). Radiographs, CT/MRI, peri-operative complications, VAS, SF-12, and ODI were measured.
Results: Average follow up was 22 months. In Group-1 and Group-2, respectively: Mean coronal Cobb angle corrected 12.6° and 5.8°; Mean regional lumbar lordosis improved 11.1° and 3.8°; Pelvic incidence minus lumbar lordosis mismatch corrected to within +/−9° in 46% and 0% of patients; Mean VAS improved from 5.4 to 2.8 and 6.3 to 1; Mean ODI improved 19% and 22%. Improvements were found in SF-12 PCS and MCS scores.
Conclusions: Both open and percutaneous posterior techniques following LLIF significantly improved clinical outcomes. Open procedures resulted in significantly better radiographic improvements but also higher complication rates. LLIF with percutaneous posterior fixation, without decompression, should be considered part of the algorithm in select ADS patients with remaining compensatory mechanisms and understanding that greater degrees of correction may require an open, more extensive approach.

1. Introduction

Adult degenerative scoliosis (ADS) is a prevalent issue among the aging population, occurring in approximately 6% of people over the age of 50.[1] Classical clinical presentations often include back pain, truncal imbalance, and radicular symptoms. Conservative management is recommended as an initial treatment, however outcomes are frequently unacceptable.[2] In patients whom have failed non-operative treatments, adult degenerative scoliosis presents significant surgical challenges. Iatrogenic instability, recurrent stenosis, and progression of deformity may occur with decompression alone for adult degenerative scoliosis, even in patients with minimal pre-existing instability. An instrumented arthrodesis is often indicated to correct coronal and sagittal imbalances, commonly performed via a posterior approach in combination with other corrective methods.[3–6] Some controversy remains over which surgical methodology most benefits ADS patients while minimizing surgical risks, particularly in patients of advanced age.

Current literature has shown that interbody fusion is an effective and often important adjunct to achieving fusion and deformity correction in adult scoliosis.[7,8] Several different approaches to interbody fusion have been utilized, including posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF), and anterior lumbar interbody fusion (ALIF). However, the transpsoas lateral lumbar interbody fusion (LLIF) is an increasingly popular method of interbody fusion that uses a less invasive approach for this pathology.[9,10] This technique of lateral-based discectomy and interbody cage placement generally allows for indirect neurological decompression with less tissue trauma, minimal blood loss, typically shorter operation times, less wound complications, placement of a larger cage versus posterior-based interbody techniques, and earlier patient mobilization.[11,12]

Studies have shown that LLIF with instrumented arthrodesis is an effective method of deformity correction in ADS[13] and that restoring

* Corresponding author.
E-mail address: jattenel@hawaii.edu (J. Attenello).

https://doi.org/10.1016/j.jor.2018.03.017
Received 30 January 2018; Accepted 18 March 2018
Available online 20 March 2018

proper sagittal alignment plays a pivotal role in preventing poor clinical outcomes of pain and disability.[14] One spino-pelvic alignment parameter of particular importance in deformity correction is the pelvic incidence (PI), and ensuring postoperative radiographs have a lumbar lordosis (LL) within $+/-9^{\circ}$ of pelvic incidence has been shown to correlate with good postoperative health-related quality of life scores.[15] However, literature comparing radiographic and clinical outcomes of ADS treated by open versus percutaneous pedicle screw instrumentation, are limited, particularly when treated with short segment fixation (remaining within lumbar spine), a unique feature of this study

This retrospective study compares clinical outcomes and radiographic correction of coronal deformity and regional lumbar lordosis in degenerative scoliosis consecutive patients from a single institution, treated with LLIF combined either with percutaneous (without decompression) versus open pedicle screw instrumentation. Of particular relevance during the transition to value-based healthcare delivery, it is important to note that this study has an added focus on the use of short segment posterior fixation in nearly all cases, where the upper instrumented vertebra (UIV) remained within lumbar spine in all percutaneous cases and in all but 3 open cases (2 UIV stopped at T11, 1 case stopped at T12).

2. Materials and methods

This study was a retrospective, institutional review board-approved, evaluation of adult degenerative scoliosis treated by three surgeons at University of California, San Diego Medical Center. From 2009 to 2012, twenty-two patients underwent extreme lateral interbody fusion (XLIF; Nuvasive Inc, San Diego, CA) with supplemental open (laminectomies, partial or complete facetectomies, and deformity correction) versus percutaneous instrumentation. Inclusion criteria included the following: 1) symptomatic ADS with Cobb angle of at least 10°; 2) Preoperative and postoperative radiographs of involved segments/levels and femoral head; 3) Preoperative and postoperative health related quality of life scores (VAS, ODI, SF-12) at appropriate follow up time points; 4) At least 40 years of age; 5) Minimum of 1 year follow up. Exclusion criteria included 1) deformity due to infection or malignancy, 2) severe osteoporosis. 22 patients met the inclusion and minimum follow up criteria. This review included all patients treated who met the appropriate inclusion criteria, not based on general surgeon discretion. Additionally, there were no significant differences between groups demographically, aiding the validity of the comparisons. Patients were followed for an average of 22 months. Data was collected at months 3, 6, 12, and 24 after surgery. Radiographic measurements, lumbopelvic parameters, and validated clinical outcome scores were obtained preoperatively and at follow-up for comparison purposes. Complications were recorded.

The average patient age was 68 years (range 47–85 years), and included 5 men and 17 women [Table 1]. Fifteen patients had apex-left deformity, and seven had apex-right. No patients were active smokers at the time of surgery. Six patients, all in the open group, were revisions, having undergone prior lumbar spine surgery at one or more levels: including prior decompression and instrumented fusion (5) and one with LLIF. All patients in Group 1 (open) had laminectomies performed, and all 6 revision cases had revision decompressive laminectomies, facetectomies, and foraminotomies.

Interbody fusion was completed using the extreme lateral interbody fusion (XLIF; Nuvasive Inc, San Diego, Ca) technique via a retroperitoneal or retropleural approach as described by Ozgur et al.[10]. Importantly, all laterally placed interbody spacers were 10° lordotic and 18 mm wide. Interbody PEEK grafts were supplemented either with Osteocel Plus allograft cellular bone matrix (NuVasive, Inc., San Diego, CA), or recombinant human bone morphogenetic protein (rhBMP-2; Medtronic Sofamor Danek, Minneapolis, MN) plus Formagraft (NuVasive, Inc., San Diego, CA). Lateral approaches were made from the concave side. Posterior instrumentation involved traditional open versus percutaneous placement of transpedicular screws and rods (NuVasive, Inc., San Diego, CA; Depuy Synthes Spine, Raynham, MA; Sofamor Danek Medtronic Spine). In the open group, all posterior fusions included local laminectomy bone often supplemented by allograft demineralized bone matrix, if quantity was not sufficient. In the percutaneous group, no formal fusions were performed. A total of 62 levels, from 2 to 4 per patient across T11-L4/5 (average of 3 levels) were treated using XLIF. Validated clinical outcome scores were collected on all patients preoperatively and at follow-up. Outcome scores included the visual analog pain score (VAS), short form-12 (SF-12), and Oswestry Disability Index (ODI). All complications were recorded as any deviation from a normal postoperative course.

2.1. Statistical analysis

Differences in patient demographics and baseline preoperative and postoperative clinical outcome and radiographic changes were analyzed using paired parametric *t*-test. Preoperative and postoperative changes in clinical and radiographic parameters were compared between groups using unpaired parametric *t*-test. Analysis was performed using Prism 6.0 (GraphPad Inc, La Jolla, CA). Significance level was set at $p < 0.05$.

3. Results

The mean duration of follow-up was 21 months (range, 13–28 months) for the patients in Group 1 (open) and 24 months (range, 23–26) for the patients in Group 2 (percutaneous). Data was collected at months 3, 6, 12, and 24 after surgery. In Group 1 (open), all patients had laminectomies and *six cases were revisions*. Radiographically, both groups demonstrated statistically significant coronal correction after LLIF and instrumentation (Table 2). Mean preoperative coronal Cobb

Table 1
Demographics.

Parameter	Open (n = 13)	Perc (n = 9)	p value
Age, mean (SEM)	68 (3.3)	68 (2.6)	0.95
No. of male:female.	2: 11	3: 6	
No. of scoliosis apex, Right:Left	4: 9	3: 6	
VAS Leg (SEM)	4.3 (2.3)	8 (0.8)	0.12
VAS back (SEM)	5 (2.5)	7.2 (0.9)	0.35
ODI (SEM)	49.5 (3.6)	41.2 (6.0)	0.22
SF-12: PCS (SEM)	33.5 (4.7)	31.4 (2.6)	0.54
SF-12: MCS (SEM)	46.8 (4.2)	46.8 (5.7)	1.00
Lumbar Lordosis, Deg (SEM)	30.6 (3.1)	30.5 (4.1)	0.98
Coronal Cobb Angle, Deg (SEM)	24.5 (2.3)	19.3 (2.2)	0.12

Table 2
Radiographic parameters.

Measurement	Open	Percutaneous	p value
Cobb Angle (degrees)			
pre-op	24.45	19.24	0.12
post-op	11.82	13.41	0.53
change	−12.63	−5.83	0.048
p value (pre-op to post-op)	0.001	0.0004	N/A
Lumbar Lordosis (degrees)			
pre-op	30.61	30.49	0.98
post-op	41.69	34.31	0.15
change	11.08	3.82	0.036
p value (pre-op to post-op)	0.0003	0.11	N/A
PI-LL (degrees)			
pre-op	16.08	15.43	0.85
post-op	6.6	12.87	0.0049
change	9.48	2.61	0.04
p value (pre-op to post-op)	0.0029	0.0024	N/A

angle was 24.4° (range 11–38°) in the open group and 19.2° (range 12–30°) in percutaneous group. Postoperatively, the coronal correction in the open group (12.6°) was significantly greater than the correction in the percutaneous group (5.8°, Table 2). Mean regional lumbar lordosis was similar preoperatively in the open group (30.6°) and percutaneous group (30.5°). Postoperatively, the open group had a significantly greater improvement in lumbar lordosis (11.1°) compared to the percutaneous group (3.8°, p = 0.036; Table 2). Pelvic incidence minus lumbar lordosis (PI-LL) improved postoperatively to a mean of 6.6° in the open group, compared to 12.9° in the percutaneous group. 6 patients in the open group (46%) who were considered mismatched preoperatively, became "matched" (e.g. PI-LL goal within 9°) postoperatively, but PI-LL mismatch persisted in the percutaneous patients postoperatively.

Peri-operative complications occurred *only in the open group*, including two wound infections (15%; 1 revision case, 1 primary case) and one dural tear (8%). Mean VAS significantly improved from 5.4 to 2.8 and 6.3 to 1, in Group 1 and Group 2 respectively; Mean VAS leg pain scores improved from 4.3 to 1.3 and from 6.7 to 0.8; and mean VAS back pain scores improved from 5 to 1 and from 6.8 to 1. Preoperative disability scores were higher in the open group, but mean change in ODI improved similarly, from 50% to 31% in Group 1, compared to 41% to 19% in Group 2. In Group 1 and Group 2 respectively, mean SF-12 PCS score increased from 34 to 40 and from 31 to 44; and mean SF-12 MCS score increased from 47 to 50 and from 47 to 57. Significant improvements in VAS, SF-12 PCS, and ODI scores occurred in both groups. The percutaneous group experienced significantly greater improvement in VAS pain scores (p = 0.04, Table 3) while radiographic parameters improved more in the open group.

4. Discussion

Traditional open surgical approaches for adult patients with scoliosis improve pain, function, and quality of life, but carry a perioperative risk profile that could negatively impact a successful surgical result, and its cost-effectiveness.[16–19] Open posterior decompression and instrumented fusion for degenerative scoliosis is associated with increased operative times and blood loss, is technically challenging, particularly in revision cases, and has complication rates of up to 45% or more.[20] Though the ultimate surgical outcome may not be compromised, this can be costly to patients and society, and methods to minimize direct and indirect costs of care in this patient population remains an important economic priority, particularly in a value-based health care system. Use of the less invasive lateral approach for interbody fusion may decrease surgical morbidity compared to the traditional anterior approach. Isaacs et al. performed a prospective, multicenter study[21] and reported that the perioperative morbidity of XLIF (Nuvasive Inc, San Diego, CA) in the treatment of adult degenerative scoliosis compares favorably to more invasive techniques, with outcomes that are similar or improved compared to their open counterparts. Youssef and colleagues[22] found similar benefits of fewer complications and quicker recoveries, using lateral interbody fusions in patients with lumbar degenerative disease.

Table 3
Clinical outcomes.

Measurement	Open	Percutaneous	p value
Mean VAS			
pre-op.	5.4	6.3	0.43
post-op	2.8	1	0.07
change	−2.6	−5.5	0.04
p value (pre-op to post-op)	0.006	0.001	N/A
Mean ODI			
pre-op	49.53	41.19	0.22
post-op	31.14	18.83	0.34
change	−18.39	−22.35	0.76
p value (pre-op to post-op)	0.05	0.07	N/A
Mean PCS			
pre-op	33.51	31.42	0.69
post-op	40.35	44.4	0.41
change	6.84	12.98	0.37
p value (pre-op to post-op)	0.16	0.004	N/A
Mean MCS			
pre-op	46.78	46.76	0.99
post-op	49.9	57.32	0.17
change	3.12	10.56	0.43
p value (pre-op to post-op)	0.58	0.2	N/A

The use of LLIF for interbody fusion in combination with *open or percutaneous* posterior instrumentation yielded good clinical results in the present study. Clinical outcome scores including VAS back and leg pain scores, ODI, and SF-12 did not demonstrate a statistically significant difference between the two groups, most likely because the study was not powered to detect these potential differences. However, a greater mean difference for VAS back pain, ODI, and PCS was observed within the percutaneous group. The percutaneous group achieved these results without any formal open posterior decompression, and by using shorter posterior constructs – keeping the UIV in the lumbar spine, *and* without significantly improving lumbar lordosis or altering PI-LL mismatch. This implies that: a) indirect neural decompression/mechanical stabilization relieved symptoms and improved function in this series of patients, regardless of the location of symptomatic stenosis or degree of spondylosis; and b) that strictly speaking, PI-LL mismatch may not be a primary contributor to disability in this cohort of patients, as patients' remaining compensatory mechanisms (e.g hips/pelvic retroversion) were able to successfully achieve improved outcomes/maintain sagittal profile without increased lordosis in the percutaneous group. Though both groups improved similarly in terms of ODI scores, greater PCS score improvements in the percutaneous group implies a higher functional level. This may be attributable to a decreased baseline ODI in the percutaneous group, indicating less disability, in addition to contributions from a shorter fusion constructs, smaller initial curves, and shorter recovery time. In contrast, significantly more radiographic improvement was seen in the open group in both coronal and sagittal planes. Minimal increase in lordosis occurred in the percutaneous group, and coronal correction was 5.8° in the percutaneous group versus 12.6° in the open group. Notably, starting coronal cobb was substantially (21%) less in the percutaneous versus open group, at 19.2° versus 24.4°, respectively, possibly indicating surgeon bias in decision-making for approach, but is consistent with prior studies on mild to moderate spinal deformity management using less invasive surgical methods. Each LLIF cage used in this study was 18 mm wide and had the same degree of lordosis (10°). As may be expected, the addition of open laminectomies/facetectomies produced substantially greater improvements in *both* coronal and sagittal planes. These data have led to several questions that may impact ADS treatment algorithms. Future studies should evaluate whether posterior percutaneous combined with different degree lordotic cages can improve lordosis, achieve better ability to match incidence to lordosis, and/or achieve the same outcomes. Future studies are also needed to determine the limits of percutaneous fixation without decompression, and to evaluate exactly when an open versus less invasive decompression may be required when combined with different cage sizes/heights/lordosis (e.g. hyperlordotic/anterior column realignment (ACR)). Interestingly, leg pain scores were not significantly different or "better" postoperatively in the open group, as one might expect with direct decompression of the neural elements. Data are somewhat limited, however, by the number of revisions in that group (e.g. 6 of 13 patients were revisions) and possibly other factors, such as the preoperative leg pain scores and duration of leg pain in the open group. There were no revisions in percutaneous group. Increased patient numbers, using different outcome measures, and more equal distributions across treatment groups would increase the ability to capture these notable differences.

The advantages of indirect decompression by larger (e.g. lateral)

interbody grafts siting on the stronger apophyseal ring is not new. In this series, complex patterns of severe central, subarticular, and neuroforaminal stenosis were present in both groups, but percutaneous fixation did not seem to negatively impact the measured clinical outcomes. Disc height restoration due to the larger graft size, particularly compared to a collapsed preoperative disc space height, as well as graft position in the sagittal plane, may independently (and together) contribute enough to the extent of indirect decompression to significantly improve clinical symptoms.[23] Correction of rotation via ligamentotaxis are additional means by which a lateral interbody cage can drive deformity correction and indirect decompression of the neural elements, thus contributing to resolution of neurogenic symptoms. Although longer follow up data and late MRI evaluations may be helpful to determine canal improvements and need for revisions, it is clear that at nearly 2 years, outcomes remain good without current need for revision. Predicting cage size, position in the interbody space, and how much disc height restoration is needed to improve outcomes in ADS of varying complexities remains less defined in percutaneously-treated patients[24] Importantly, the current percutaneous treatment method was tested only on moderate sized ADS curves averaging 19°. Although limitations of this MIS method are becoming increasingly clear in ADS patient treatment algorithms,[25] this study is not designed to "test" the limits of method. Realizing these limitations, this method of treatment in the current study, using LLIF and percutaneous fixation for mild to moderate ADS curves, is viewed more as an integral part of the surgical decision-making algorithm for ADS patients rather than a weighted selection bias of the treating surgeons.

While correction of deformity was greater in the open group, we also observed higher complication rates. Complication rates are expected to be higher during open adult scoliosis surgery, particularly since all revision cases were in the open group. Though evidence suggests that vancomycin powder use in posterior lumbar spine surgeries can markedly decrease infection rate,[26] no vancomycin powder was used in these wounds. This, in addition to increased surgical time, tissue dissection, and several other factors may contribute to the observed higher complication rates and worse postoperative pain scores in the open group. Interestingly, while their average curves were smaller, preoperative pain scores were higher and VAS pain scores were significantly more improved in the percutaneous group. Worse disability scores were found in the open group preoperatively. It is interesting to postulate what factors may improve pain scores to that extent in the percutaneous group, including less paraspinal muscle (e.g. multifidus) dissection/injury, decreased blood loss and OR time, fewer complications, or other structural or psycho-social factors contributing to preoperative pain scores. Nonetheless, in carefully selected patients, less morbidity in adult scoliosis surgery may be seen using less invasive techniques, with similar outcomes compared to the open approach.

Weaknesses of this study include its retrospective nature, relatively small patient numbers, lack of long-standing radiographs for other measures of sagittal and coronal profile, and the lack of other corollary data regarding fusion rates. No revisions, however, over this time period implies fusion rates are likely within acceptable limits. Strengths of the study include the relatively long follow-up, the direct comparisons between treatment methods using the same lordotic 10° interbody grafts, shorter fusion constructs being used in nearly all cases, and the finding that percutaneously treated patients had improved pain and functional scores despite only mild coronal and little if any sagittal correction. Additionally, we found marked improvements in both sagittal and coronal deformity correction using open posterior surgical techniques and interbody grafts with the same degree of lordosis as in the percutaneous group.

5. Conclusions

The goal of this study was to compare LLIF combined with open versus percutaneous posterior instrumented approaches in the treatment of adult degenerative scoliosis. In this series of patients, significant clinical improvement was noted in multiple validated outcome tools in both groups, but key differences were observed radiographically despite all interbody cages having identical lordosis. All in the percutaneous group, and all but 3 in open group, underwent short segment posterior instrumented fusions limited to the lumbar spine only. Fewer complications were seen in the percutaneous group. This should be considered when interpreting the data for ADS and the treatment rationale for the use of percutaneous fixation, and this series adds to a growing body of data supporting the efficacy of LLIF with instrumented arthrodesis in the treatment of adult degenerative scoliosis. Percutaneous posterior fixation, *without decompression*, should be considered part of the algorithm in select patients with degenerative scoliosis, understanding that differences in patient pathologies, global sagittal/coronal balance, number of levels fused, and curve characteristics may necessitate an open approach.

Conflict of interest

None.

References

1. Vanderpool DW, James JI, Wynne-Davies R. Scoliosis in the elderly. *J Bone Joint Surg.* 1969;51(3):446–455.
2. Tribus CB. Degenerative lumbar scoliosis: evaluation and management. *J Am Acad Orthopaedic Surg.* 2003;11(3):174–183.
3. Aebi M. The adult scoliosis. *Eur Spine J.* 2005;14(10):925–948.
4. Daffner SD, Vaccaro AR. Adult degenerative lumbar scoliosis. *Am J Orthopedics.* 2003;32(2):77–82.
5. Birknes JK, White AP, Albert TJ, et al. Adult degenerative scoliosis: a review. *Neurosurgery.* 2008;63(3):A94–A103.
6. Bradford DS, Tay BKB, Hu SS. Adult scoliosis: surgical indications, operative management, complications, and outcomes. *Spine.* 1999;24(24):2617–2629.
7. Gelalis ID, Kang JD. Thoracic and lumbar fusions for degenerative disorders: rationale for selecting the appropriate fusion techniques. *Orthop Clin North Am.* 1998;29(4):829–842.
8. Gupta MC. Degenerative scoliosis: options for surgical management. *Orthop Clin North Am.* 2003;34(2):269–279.
9. Pimenta L. Lateral endoscopic transpsoas retroperitoneal approach for lumbar spine surgery. *VIII Brazilian Spine Society Meeting.* Belo Horizo te, Minas Gerais, Brazil2018; 2018.
10. Ozgur BM, Aryan HE, Pimenta L, et al. Extreme lateral interbody fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. *Spine J.* 2006;6(4):435–443.
11. Eck JC, Hodges S, Humphreys SC. Minimally invasive lumbar spinal fusion. *J Am Acad Orthop Surg.* 2016;15(6):321–329.
12. Benglis DM, Elhammady MS, Levi AD, et al. Minimally invasive anterolateral approaches for the treatment of back pain and adult degenerative deformity. *Neurosurgery.* 2018;63(Suppl. 3):191–196.
13. Mundis GM, Akbarnia BA, Phillips FM. Adult deformity correction through minimally invasive lateral approach techniques. *Spine (Phila Pa 1976).* 1976;35(Suppl. 26):S312–S321.
14. Ames CP, Smith JS, Scheer JK, et al. Impact of spinopelvic alignment on decision making in deformity surgery in adults. A review. *J Neurosurg Spine.* 2012;16:547–564.
15. Schwab F, Lafage V, Patel A, Farcy JP. Sagittal plane considerations and the pelvis in the adult patient. *Spine (Phila Pa 1976).* 2009;34(August (17)):1828–1833.
16. Daubs MD, Lenke LG, Cheh G, et al. Adult spinal deformity surgery: complications and outcomes in patients over age 60. *Spine.* 2007;32(20):2238–2244.
17. Cho KJ, Suk SI, Park SR, et al. Complications in posterior fusion and instrumentation for degenerative lumbar scoliosis. *Spine.* 2007;32(20):2232–2237.
18. Uddin OM, Haque R, Sugrue PA, et al. Cost minimization in treatment of adult degenerative scoliosis. *J Neurosurg Spine.* 2015;23(December (6)):798–806.
19. Kim YB, Lenke LG, Kim YJ, et al. The morbidity of an anterior thoracolumbar approach: adult spinal deformity patients with greater than five-year follow-up. *Spine.* 2009;34:822–826.
20. Pateder DB, Kebaish KM, Cascio BM, Neubaeur P, et al. Posterior only versus combined anterior and posterior approaches to lumbar scoliosis in adults: a radiographic analysis. *Spine.* 2007;32(14):1551–1554.
21. Isaacs RE, Hyde J, Goodrich JA, Rodgers WB, et al. A prospective, nonrandomized, multicenter evaluation of extreme lateral interbody fusion for the treatment of adult degenerative scoliosis: perioperative outcomes and complications. *Spine.* 2010;35(26):S322–S330.
22. Youssef JA, McAfee PC, Patty CA, et al. Minimally invasive surgery: lateral approach interbody fusion: results and review. *Spine.* 2010;35(26):S302–S311.
23. Kepler CK, Huang RC, Sharma AK, et al. Factors influencing segmental lumbar lordosis after lateral transpsoas interbody fusion. *Orthop Surg.* 2012;4:71–75.
24. Wang MY, Mummaneni PV, Fu KM, et al. Less invasive surgery for treating adult spinal deformities: ceiling effects for deformity correction with 3 different techniques. *Neurosurg Focus.* 2014;36(May (5)):E12.
25. Mummaneni PV, Shaffrey CI, Lenke LG, et al. The minimally invasive spinal deformity surgery algorithm: are producible rational framework for decision making in minimally invasive spinal deformity surgery. *Neurosurg Focus.* 2014;36(May (5)):E6.
26. Sweet FA, Roh M, Sliva C. Intrawound application of vancomycin for prophylaxis in instrumented thoracolumbar fusions: efficacy, drug levels, and patient outcomes. *Spine (Phila Pa 1976).* 2011;36(November (24)):2084–2088.