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ORIGINAL ARTICLE

A comparative cohort study of surgical approaches for adult spinal deformity at a minimum 2-year follow-up

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Abstract

Study design This study was a retrospective multi-center comparative cohort study.

Materials and methods A retrospective institutional database of operative adult spinal deformity patients was utilized. All fusions > 5 vertebral levels and including the sacrum/pelvis were eligible for inclusion. Revisions, 3 column osteotomies, and patients with < 2-year clinical follow-up were excluded. Patients were separated into 3 groups based on surgical approach: 1) posterior spinal fusion without interbody (PSF), 2) PSF with interbody (PSF-IB), and 3) anteroposterior (AP) fusion (anterior lumbar interbody fusion or lateral lumbar interbody fusion with posterior screw fixation). Intraoperative, radiographic, and clinical outcomes, as well as complications, were compared between groups with ANOVA and χ^2 tests.

Results One-hundred and thirty-eight patients were included for study (PSF, n = 37; PSF-IB, n = 44; AP, n = 57). Intraoperatively, estimated blood loss was similar between groups ($p = 0.171$). However, the AP group had longer operative times (547.5 min) compared to PSF (385.1) and PSF-IB (370.7) ($p < 0.001$). Additionally, fusion length was shorter in PSF-IB (11.4) compared to AP (13.6) and PSF (12.9) ($p = 0.004$). There were no differences between the groups in terms of change in alignment from preoperative to 2 years postoperative. There were no differences in clinical outcomes. While postoperative complications were largely similar between groups, operative complications were higher in the AP group (31.6%) compared to the PSF (5.4%) and PSF-IB (9.1) groups ($p < 0.001$).

Conclusion While there were differences in intraoperative outcomes (operative time and fusion length), there were no differences in postoperative clinical or radiographic outcomes. AP fusion was associated with a higher rate of operative complications.

Keywords Adult spinal deformity · Surgical approaches · Lumbar fusion · Posterior spinal fusion · Interbody fusion · Outcomes · Complications · Alignment

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Introduction

Spinal fusion is a common surgical treatment for adult spinal deformity (ASD), including spondylolisthesis, degenerative disc disease, and spinal stenosis [1, 2]. Surgical treatment aims to reduce instability and restore lordosis and sagittal balance in order to reduce pain, optimize function, and correct degenerative deformities [1]. In the past three decades, there has been a significant increase in the number of spinal fusions performed globally, with the highest incidence occurring in the United States [3]. Multiple studies assessing trends in lumbar fusion procedures in the United States have described greater than two-fold increases in the utilization of lumbar spinal fusions [4, 5], with a 118% increase in utilization between 1998 and 2014, outpacing the rapid growth of even hip and knee arthroplasty.

Accompanying this increase in the utilization of lumbar spinal fusion has been an increase in the number of techniques, implants, instruments, and approaches used to perform this procedure [2]. These surgical techniques/approaches include posterior fusion without interbody, posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF), anterior lumbar interbody fusion (ALIF), and lateral or extreme lateral interbody fusion (LLIF/XLIF). The use of an interbody has gained increased popularity as it allows the surgeon to increase intervertebral height, indirectly decompress the neural foramen, achieve strong circumferential fusion, and restore sagittal balance by increasing lumbar lordosis [6–8].

While there are multiple different surgical approaches and techniques to address ASD of the lumbar spine, all with purported advantages and disadvantages, there are a limited number of studies comparing outcomes between the different available approaches. The goal of the current study was to compare posterior spinal fusion without interbody (PSF), posterior spinal fusion with interbody (PSF-IB), and anteroposterior (AP) fusion (anterior lumbar interbody fusion and/or lateral lumbar interbody fusion) in terms of intraoperative, postoperative, and radiographic outcomes to determine the relative risks and benefits associated with each procedure at the 2-year postoperative timepoint. We hypothesized that there would be minimal differences between these approaches in terms of postoperative outcomes.

Materials and methods

Study design

Institutional Review Board approval was attained prior to the initiation of this study (IRB 2018-1142). Consent was obtained prior to study enrollment. This study was a retrospective multi-center study assessing the outcomes of three different surgical approaches on intraoperative, radiographic, and clinical outcomes, as well as complications, following lumbar spinal fusion. All operations were performed by high-volume fellowship trained spine surgeons. Surgical approaches under study included PSF, PSF-IB, and AP. In the AP group, 30 (52.6%) procedures were performed on the same day, while 27 (47.4%) were performed in a staggered fashion. No specific criteria were utilized for selecting one approach over another. AP patients underwent anterior release and interbody cage placement or lateral interbody cage placement followed by posterior screw fixation.

Patients were identified using an institutional database that aggregates results from patients undergoing treatments of ASD from Oct 2008 to Jun 2015. The inclusion criteria were as follows: 1) male and female patients age > 18, 2) primary spinal fusion, 3) > 5 level fusion, 4) fusion including sacrum/pelvis, 5) preoperative diagnosis of adult spinal deformity as previously defined (PMID: 16,946,628), and 6) surgical approach was PSF, PSF-IB, or AP fusion. Patients were excluded if 1) age < 18, 2) < 5 level fusion was performed, 3) the fusion did not include the pelvis/sacrum, 4) index surgery was a revision, 5) a three column osteotomy (CO) was performed, 6) a surgical approach other than PSF, PSF-IB, or AP was utilized, or 7) if they had a diagnosis aside from ASD, such as iatrogenic flatback deformity or neuromuscular scoliosis.

Intraoperative/postoperative outcomes and complications

Intraoperative outcomes included operative time (minutes), number of levels fused, number of interbody devices placed, and estimated blood loss (EBL). Postoperative outcomes included hospital length of stay (LOS), and multiple patient-reported outcomes measures (PROMs), including Physical Component Summary (PCS), Mental Component Summary (MCS), Scoliosis Research Society 22 (SRS-22), Oswestry Disability Index (ODI), Lumbar Stiffness Disability Index (LSDI), and EuroQOL-5D (EQ5D). PROMs were assessed preoperatively and at 2 years postoperative.

Complications were grouped and assessed by complication severity and complication type. Complications were classified by severity based on the perceived patient impact as follows: any type of complication (including adverse events), any complication (excluding adverse events), major complications (with or without reoperation), major complication requiring reoperation, minor complication. Complications were also assessed by complication type, as follows: cardiopulmonary, implant-related, infection, neurologic, operative, radiographic, renal, wound (Table 1).

Table 1 Complications monitored in the current study

Complications	
Cardiopulmonary	*Neurologic*
Acute respiratory distress syndrome	Bowel/bladder deficit
Arrhythmia	Epidural hematoma
Atelectasis	Femoral neuralgia
Cardiac arrest	Mental status change
Congestive heart failure	Motor deficit
DVT	Sensory deficit
MI	Nerve root injury
PE	Optho
Pleural effusion	Radiculopathy
Reintubation	SCI myelopathy
	Seizure
	Stroke
Gastrointestinal	*Operative*
Cholecystitis	Bowel perforation
Dysphagia	Dural tear
Gastrointestinal bleed	Excessive bleeding
Ileus	Lymphocele
	Monitoring anomaly
	Pedicle fracture
	Pleural injury
	Positioning
	Retained sponge
	Vascular injury
	Vertebral fracture
	Visceral injury
Implant	*Wound*
Fracture	Dehiscence
Loosening/dislocation	Erythema
Malposition	Drainage
Painful	Hematoma/seroma
Prominence	Incisional hernia
Infection	*Radiographic*
C diff infection	ASD
Superficial infection	Coronal imbalance
Deep infection	Sagittal imbalance
Pneumonia	Proximal junctional kyphosis
Sepsis	Distal junctional kyphosis
Urinary tract infection	Pseudo
Renal failure	

Complications were compared between the PSF, PSF-IB, and AP groups when assessed by both complication severity and complication type.

To ensure consistency across sites and to avoid over and under reporting due to local interpretation, each submitted complication was reviewed by a group of experienced spine surgeons and severity was adjusted based on real impact as reported by the site. This process was done systematically as part of the ongoing study to ensure quality of the data reported.

Radiographic outcomes

Full-length, free standing preoperative and postoperative lateral radiographs were collected. Identification and mapping of various anatomical landmarks were performed at a single center, using a dedicated and validated software (SpineView, ENSAM Laboratory of Biomechanics) to calculate the following parameters: pelvic incidence (PI), pelvic tilt (PT), lumbar lordosis (LL), thoracic kyphosis (T4–T12), cervical lordosis (C2-C7), sagittal vertical axis (SVA) from C2-C7 and from C7–S1, and T1-Pelvic-Angle (TPA).

Statistical analysis

Statistical analysis was performed using SPSS 20.0 (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk). Radiographic and clinical outcomes, as well as complications, were compared between groups with ANOVA and χ^2 tests.

Source of funding

No external funding was utilized for the completion of this study.

Results

After applying our inclusion/exclusion criteria, 138 patients were included for study (n = 37 in PSF; n = 44 in PSF-IB; n = 57 in AP). Groups were similar with respect to male to female ratio, BMI, and ASA, but there were statistically significant differences in patient age between the groups (Table 2).

Intraoperative outcomes

When comparing intraoperative outcomes, the AP group (547.5) demonstrated significantly longer operative times compared to the PSF (385.1) and PSF-IB groups (370.7) ($p < 0.0014$). Significantly fewer levels were fused in the PSF-IB groups (11.4) compared to the PSF (12.9) and AP groups (13.6) ($p = 0.004$). Additionally, a greater number of interbody fusion levels were performed in the AP group (3.54) than the PSF-IB group (1.59) ($p < 0.001$). No statistically significant differences were identified between the groups with respect to estimated blood loss (EBL) (Table 3).

Table 2 Preoperative patient demographics

Preoperative demographic	PSF	PSF-IB	AP	Total or average	*P*-value
Male	6 (16.2%)	9 (20.5%)	6 (10.5%)	138	0.380
BMI	26.7	27.33	25.62	26.45	0.196
Age	63.23	67.49	60.39	63.41	< 0.001
ASA	2.49	2.29	2.22	2.32	0.120

PSF = posterior spinal fusion; PSF-IB = posterior spinal fusion with interbody; AP = anteroposterior; BMI = body-mass index; ASA = american society of anesthesiologists

Table 3 Comparison of intraoperative findings between the groups

Intraoperative factor	PSF	PSF-IB	AP	Average	*P*-value
Operative time	385.1	370.7	547.5	448.2	< 0.001
Fusion levels	12.9	11.4	13.6	12.7	0.004
Interbody levels	–	1.6	3.5	2.6	< 0.001
Estimated blood loss	1593.2	1923.2	1545.6	1673.3	0.171

PSF = posterior spinal fusion; PSF-IB = posterior spinal fusion with interbody; AP = anteroposterior

Table 4 Comparison of LOS and PROMs between the groups

PROMs	PSF	PSF-IB	AP	Average	*P*-value
LOS	6.92	7.68	8.53	7.8	0.177
PCS	11.8	9.5	10.6	10.5	0.585
MCS	5.2	5.3	5.2	5.2	0.999
SRS-22	1.2	1.0	1.0	1.1	0.348
ODI	− 24.7	− 21.2	− 20.3	− 21.7	0.428
LSDI	− 2.9	− 6.1	− 1.5	− 3.0	0.738
EQ5D	0.1	0.1	0.1	0.1	0.853

PROM = patient-reported outcomes measure; PSF = posterior spinal fusion; PSF-IB = posterior spinal fusion with interbody; AP = anteroposterior; LOS = length of stay; PCS = physical component summary; MCS = mental component summary; SRS-22 = Scoliosis Research Society 22; ODI = Oswestry disability index; LSDI = lumbar stiffness disability index; EQ5D = EuroQOL-5D

Clinical outcomes and complications

With respect to health-related quality of life measures, no differences were identified between the groups when comparing change in measures from preoperative to 2 years postoperative in terms of any of the measures included in this study (Table 4). With respect to complications, no differences were identified between the groups in terms of overall complications, major complications, or minor complications. No differences were identified in terms of complications when assessed by complication type, with the exception of operative complications. While postoperative complications were largely similar between groups, operative complications were higher in the AP group (31.6%) compared to the PSF (5.4%) and PSF-IB (9.1) groups ($p < 0.001$) (Table 5). This is largely attributed to the high number of patients in the AP group with > 4L of EBL.

Radiographic outcomes

Preoperatively, there was no difference between the groups in terms of PI, PT, LL, T4-T12 or C2-C7 alignment, C2-C7 or C7–S1 SVA, or PA (Table 5). At the 2-year postoperative endpoint, there were no differences in the change in alignment from preoperative to the 2-year endpoint in any of the alignment parameters assessed in this study (Tables 6 and 7).

Discussion

Increases in the utilization of spinal fusion for ASD have been met with rapid innovation in surgical techniques and approaches to accomplish this procedure. However, there is still only limited evidence assessing the differences, if any, between the multitude of different surgical techniques and approached described. Given the increasing utilization of each of these techniques, it is important for surgeons to understand the relative risks and benefits associated with each procedure in order to better dictate treatment preferences. In the current study, we assessed differences in intraoperative, postoperative, and radiographic outcomes between PSF, PSF-IB, and AP. Preoperative demographics and spinal deformities were similar between the groups, with the exception of a slightly increased age in the PSF-IB group. Intraoperatively, there was no difference in EBL. However, there was a significant increase in operative time associated with AP, which is to be expected given the need for intraoperative patient re-positioning or staged procedures. The number of fusion levels was also significantly higher in the AP group, as was the number of interbody constructs used when comparing the AP and PSF-IB groups. There were no differences between the groups in terms of change in alignment from preoperative to 2 years postoperative in any of the radiographic measures assessed in this study. There were no differences in clinical outcomes, including LOS or PROMs, nor were there differences in the

Table 5 Comparison of complications as assessed by complication severity and complication type between the groups

	All patients		P-TLIF		P + TLIF		A + P		*p*-value total	*p*-value reop
	Total patients (%)	Total minor/major complications [reop]	Total	Minor/major [reop]	Total	Minor/major [reop]	Total	Minor/major [reop]		
Any complication	92 (66.7%)	53/65 [41]	26 (70.3%)	10/20 [13]	27 (61.4%)	17/18 [8]	39 (68.4%)	26/27 [20]	0.653	0.128
Cancer	0 (0%)		0 (0%)		0 (0%)		0 (0%)		–	–
Cardiopulmonary	19 (13.8%)	10/11 [1]	7 (18.9%)	2/5 [0]	3 (6.8%)	2/2 [0]	9 (15.8%)	6/4 [1]	0.245	0.489
Electrolyte	0 (0%)		0 (0%)		0 (0%)		0 (0%)		–	–
Gastrointestinal	11 (8%)	9/3 [2]	2 (5.4%)	2/0 [0]	3 (6.8%)	1/2 [1]	6 (10.5%)	6/1 [1]	0.632	0.674
Implant	33 (23.9%)	7/28 [15]	12 (32.4%)	0/12 [9]	12 (27.3%)	3/10 [2]	9 (15.8%)	4/6 [4]	0.148	**0.008**
Infection	10 (7.3%)	4/7 [7]	1 (2.7%)	0/1 [1]	4 (9.1%)	2/2 [2]	5 (8.8%)	2/4 [4]	0.459	0.636
Musculoskeletal	0 (0%)		0 (0%)		0 (0%)		0 (0%)		–	–
Neurologic	15 (10.9%)	11/5 [3]	1 (2.7%)	1 / 0 [0]	6 (13.6%)	6/0 [0]	8 (14%)	4/5 [3]	0.175	0.113
Operative	24 (17.4%)	13/12 [4]	2 (5.4%)	0/2 [1]	4 (9.1%)	2/2 [0]	18 (31.6%)	11/8 [3]	**0.001**	0.294
Radiographic	37 (26.8%)	19/22 [18]	11 (29.7%)	5/7 [6]	12 (27.3%)	7/6 [4]	14 (24.6%)	7/9 [8]	0.855	0.611
Renal	0 (0%)		0 (0%)		0 (0%)		0 (0%)		–	–
Vascular	0 (0%)		0 (0%)		0 (0%)		0 (0%)		–	–
Wound	0 (0%)		0 (0%)		0 (0%)		0 (0%)		–	–

Statistically significant events are indicated in bold

Table 6 Comparison of preoperative alignment measures between the groups

Alignment measure	PSF	PSF-IB	AP	Average	*P*-value
PI	54.7	54.1	53.6	54.1	0.904
PT	22.6	25.4	23.2	23.7	0.329
LL	13.0	17.1	13.1	14.3	0.459
T4-T12	−31.6	−31.5	−31.2	−31.4	0.993
C2-C7	10.5	13.2	9.8	11.0	0.536
SVA C2-C7	26.6	22.9	25.5	25.0	0.475
SVA C7–S1	56.8	62.0	42.1	52.4	0.231
TPA	20.7	23.4	19.9	21.2	0.260

PSF = posterior spinal fusion; PSF-IB = posterior spinal fusion with interbody; AP = anteroposterior; PI = pelvic incidence; PT = pelvic tilt; LL = lumbar lordosis; T4-T12 = alignment from T4-T12; C2-C7 = alignment from C2-C7; SVA = sagittal vertical axis; TPA = T1-pelvic-angle

Table 7 Comparison of change in alignment measures between the groups from preoperative to 2 years postoperative

Alignment measure	PSF	PSF-IB	AP	Average	*P*-value
PT	−1.5	−1.8	−2.8	0.7	0.721
LL	−9.5	−14.9	−17.6	0.2	0.166
T4-T12	−14.2	−18.7	−15.4	0.2	0.229
C2-C7	4.7	2.7	4.2	0.7	0.731
SVA C2-C7	5.1	5.5	3.7	0.7	0.710
SVA C7–S1	−16.1	−30.8	−36.1	0.3	0.278
TPA	−2.6	−4.3	−5.4	0.4	0.439

PSF = posterior spinal fusion; PSF-IB = posterior spinal fusion with interbody; AP = anteroposterior; PI = pelvic incidence; PT = pelvic tilt; LL = lumbar lordosis; T4-T12 = alignment from T4-T12; C2-C7 = alignment from C2-C7; SVA = sagittal vertical axis; TPA = T1-pelvic-angle

majority of postoperative complications as assessed by complication severity and complication type, with the exception of higher operative complications in the AP group. Overall, these results indicate that while there may be intraoperative differences in terms of the operative time and number of surgical levels involved in order to achieve fusion, there are no differences in radiographic or clinical outcomes associated with these different surgical procedures.

PLIF and TLIF are both utilized for the treatment of degenerative spine pathologies, such as segmental instability, recurrent disc herniations, stenosis, pseudarthrosis, and degenerative deformity. PLIF allows for optimal interbody height restoration and provides excellent posterior and 360° visualization for decompression and fusion. However, the paraspinal muscle damage associated with this approach can prolong the postoperative recovery. Furthermore, this approach is associated with increased risk of neural and dural injury, difficulty correcting coronal imbalance and restoring lumbar lordosis, and difficulty with endplate preparation. Similar to PLIF, TLIF also limits the ability to correct degenerative deformity and provides suboptimal preparation of the endplate. As opposed to PLIF, however, TLIF limits damage to the posterior ligamentous structures and paraspinal muscles, as well as decreases the risk associated with nerve root and dural injury. However, it provides limited visualization compared to PLIF [2].

LLIF is also used for degenerative pathologies in the spine. LLIF has many advantages, including a minimally invasive muscle splitting approach that may improve recovery times, excellent deformity correction and disc height restoration due to improved endplate preparation, and indirect decompression of the neural foramina [6, 8–13]. There are multiple disadvantages associated with this approach, however. This approach is difficult or contraindicated in patients with prior retroperitoneal surgery or vascular abnormalities, and it cannot be used for L5–S1 fusion or in patients with severe central canal stenosis, bony lateral recess stenosis, or high-grade spondylolisthesis. Finally, this approach is associated with a risk of injury to the lumbar plexus and iliac vessels.

ALIF, on the other hand, allows for direct decompression of the neural foramina, excellent access to L5–S1, lower risk of lumbar plexus injuries due to decreased need to mobilize the psoas muscle, the ability to use larger cage size diameters, the ability to resect the anterior longitudinal ligament, and insertion of wedge-shaped lordotic grafts [11, 14, 15]. Disadvantages of this approach include risks of visceral and vascular injuries, as well as a risk of retrograde ejaculation [2].

Posterior approaches to the spine, including PSF and PSF-IB, allow for multiplanar balance correction, but have higher morbidity, limit access to the anterior aspect of the vertebral body, and may be suboptimal in revision surgery when significant bony deformity (especially in the presence of prior graft material) obscures visualization of the vertebral anatomy [16, 17]. In the current study, there was no radiographic or clinical evidence indicating additional difficulty with interbody placement using posterior approaches. However, the reported ease of placing interbody constructs may explain why in our study and others [17], a greater number of interbody fusion levels were performed in the AP group than the PSF-IB group.

It is important to compare the results of the current study to the results of Bae et al. [17], who also compared PSF, PSF with LLIF, and PSF with ALIF. Similar to the current study, Bae et al. found that radiographically, all three surgical groups achieved similar radiographic outcomes. In opposition to our study, however, Bae et al. found that patients who underwent PSF with LLIF had lower rates of proximal junctional kyphosis and mechanical failure, as well better PROMs (less back pain and disability, increased SRS-22

scores). While it is unclear what the cause of this discrepancy is, it is possible that the longer follow-up time in Bae et al. 34.5 ± 21.7 months partially explains this finding.

In the current study, we also found a high risk of intraoperative complications associated with the AP group. This increased risk was largely attributed to a higher number of intraoperative durotomies and vascular injuries. Given the proximity of the anterior approach to the aorta, iliac vessels, and inferior vena cava, the risk of vascular injury has been reported to be as high as 23.5% with ALIF [18]. Additionally, the risk of durotomy varies widely in ASD surgery, but has been observed to be as high as 44% [19]. Given that AP fusion combines the risks of these procedures, involves two exposures, and increases operative time and invasiveness, it may explain the findings of higher complication rates associated with this procedure.

There were many limitations to the current study. Firstly, this was a retrospective study. As such, there was no randomization in patient allocation to the various surgical approaches. Therefore, there may be subtle differences in patient presentation, pathology, or anatomy that drove subtle differences in treatment choice. The fact that patients had similar preoperative demographics and deformities, however, indicates that these patient populations were largely homogeneous. Notably, however, there were significant differences in the number of surgical levels (with the AP group having the largest number of operated levels), which may impact their results of this study. Secondly, because multiple surgeons with different surgical preferences were included in this study, it is possible that subtle differences between surgeons impacted the results of this study. This is especially true in the setting of approach selection. Because the different surgical approaches were chosen based on surgeon preference, it is difficult to understand if surgical indications contributed in any way to the differences between these surgical approaches in the current study. Thirdly, while only patients with 2-year follow-up were included in this study, it is impossible to extrapolate the results of the current study to the long-term. Therefore, it is possible, though not indicated by any of the results of the current study, that there are differences in long-term outcomes between these surgical approaches. Finally, we did not assess differences in operative time between methods. Future studies should focus on the long-term outcomes between these surgical approaches to determine if there are any differences.

Conclusion

While there were differences in intraoperative outcomes between PSF, PSF-IB, and AP, including operative time and fusion length, there were no differences in postoperative clinical or radiographic outcomes. AP fusion was associated with a significantly higher rate of operative complications. However, AP fusion did not appear to significantly lower the risk of pseudarthrosis.

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Declaration

Conflict of interest There were no competing interests or conflicts of interest directly related to this study.

References

1. Mobbs RJ et al (2015) Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP LLIF ALIF. J Spine Surg 1(1):2–18
2. Reisener MJ et al (2020) Trends in lumbar spinal fusion-a literature review. J Spine Surg 6(4):752–761
3. Kim P, Kurokawa R, Itoki K (2010) Technical advancements and utilization of spine surgery–international disparities in trend-dynamics between Japan, Korea, and the USA. Neurol Med Chir 50(9):853–858
4. Rajaee SS et al (2012) Spinal fusion in the United States: analysis of trends from 1998 to 2008. Spine 37(1):67–76
5. Sheikh SR et al (2020) Can we justify it? trends in the utilization of spinal fusions and associated reimbursement. Neurosurgery 86(2):E193–E202
6. Acosta FL et al (2011) Changes in coronal and sagittal plane alignment following minimally invasive direct lateral interbody fusion for the treatment of degenerative lumbar disease in adults: a radiographic study. J Neurosurg Spine 15(1):92–96
7. Benglis DM et al (2008) Minimally invasive anterolateral approaches for the treatment of back pain and adult degenerative deformity. Neurosurgery 63(3 Suppl):191–196
8. Mundis GM, Akbarnia BA, Phillips FM (2010) Adult deformity correction through minimally invasive lateral approach techniques. Spine 35(26 Suppl):S312–S321
9. Caputo AM et al (2013) Extreme lateral interbody fusion for the treatment of adult degenerative scoliosis. J Clin Neurosci 20(11):1558–1563
10. Crawford CH et al (2015) The minimum clinically important difference in SRS-22R total score, appearance, activity and pain domains after surgical treatment of adult spinal deformity. Spine 40(6):377–381
11. Lykissas MG et al (2014) Nerve injury after lateral lumbar interbody fusion: a review of 919 treated levels with identification of risk factors. Spine J 14(5):749–758
12. Guérin P et al (2012) The lumbosacral plexus: anatomic considerations for minimally invasive retroperitoneal transpsoas approach. Surg Radiol Anat 34(2):151–157
13 Isaacs RE et al (2010) A prospective, nonrandomized, multicenter evaluation of extreme lateral interbody fusion for the treatment of adult degenerative scoliosis: perioperative outcomes and complications. Spine 35(26 Suppl):S322–S330
14. Hsieh MK et al (2015) Combined anterior lumbar interbody fusion and instrumented posterolateral fusion for degenerative lumbar scoliosis: indication and surgical outcomes. BMC Surg 15:26

15. Watkins RG, Hanna R, Chang D (2014) Sagittal alignment after lumbar interbody fusion: comparing anterior, lateral, and transforaminal approaches. J Spinal Disord Tech 27(5):253–256
16. Bhagat S et al (2013) Morbidity and mortality in adult spinal deformity surgery: Norwich Spinal Unit experience. Eur Spine J 22(Suppl 1):S42–S46
17. Bae J et al (2018) Comparative analysis of 3 surgical strategies for adult spinal deformity with mild to moderate sagittal imbalance. J Neurosurg Spine 28(1):40–49
18. Chiriano J et al (2009) The role of the vascular surgeon in anterior retroperitoneal spine exposure: preservation of open surgical training. J Vasc Surg 50(1):148–151
19 Hamouda AM et al (2024) The predictors of incidental durotomy in patients undergoing pedicle subtraction osteotomy for the correction of adult spinal deformity. J Clin Med 13(2):340