

Adjacent level disease following lumbar spine surgery: A review

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Received: 07 September 15 Accepted: 10 September 15 Published: 25 November 15

Abstract

Background: Instrumented lumbar spine surgery is associated with an increased risk of adjacent segment disease (ASD). Multiple studies have explored the various risk factors contributing to ASD that include; fusion length (especially, three or more levels), sagittal malalignment, facet injury, advanced age, and prior cephalad degenerative disease.

Methods: In this selective review of ASD, following predominantly instrumented fusions for lumbar degenerative disease, patients typically underwent open versus minimally invasive surgery (MIS), transforaminal lumbar interbody fusions (TLIFs), posterior lumbar interbody fusions (PLIFs), or rarely posterolateral lumbar instrumented or noninstrumented fusions (posterolateral lumbar fusion).

Results: The incidence of ASD, following open or MI lumbar instrumented fusions, ranged up to 30%; notably, the addition of instrumentation in different series did not correlate with improved outcomes. Alternatively, in one series, at 164 postoperative months, noninstrumented lumbar fusions reduced the incidence of ASD to 5.6% versus 18.5% for ASD performed with instrumentation. Of interest, dynamic instrumented/stabilization techniques did not protect patients from ASD. Furthermore, in a series of 513 MIS TLIF, there was a 15.6% incidence of perioperative complications that included; a 5.1% frequency of durotomy and a 2.3% instrumentation failure rate.

Conclusions: The incidence of postoperative ASD (up to 30%) is greater following either open or MIS instrumented lumbar fusions (e.g., TLIF/PLIF), while decompressions with noninstrumented fusions led to a much smaller 5.6% risk of ASD. Other findings included: MIS instrumented fusions contributed to higher perioperative complication rates, and dynamic stabilization did not protect against ASD.

Key Words: Adjacent segment disease, lumbar fusions: Transforaminal lumbar interbody fusions, posterior lumbar interbody fusions: Dynamic stabilization

Access this article online

Website:

www.surgicalneurologyint.com

DOI:

10.4103/2152-7806.170432

Quick Response Code:



INTRODUCTION

Performing lumbar spine surgery involving instrumentation increases the risk of adjacent segment disease (ASD). These operations typically include decompressions accompanied by open versus minimally invasive surgery/minimally invasive (MIS/MI) transforaminal lumbar interbody fusions (TLIFs), posterior lumbar

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How to cite this article: Epstein NE. Adjacent level disease following lumbar spine surgery: A review. *Surg Neurol Int* 2015;6:S591-9.

<http://surgicalneurologyint.com/Adjacent-level-disease-following-lumbar-spine-surgery:-A-review/>

interbody fusions (PLIFs); only rarely, are posterolateral lumbar instrumented or noninstrumented fusions (posterolateral lumbar fusion [PLF]) performed. In one series, frequencies of ASD utilizing open versus MIS instrumented fusion techniques ranged up to 30%; in another series, ASD at 164 postoperative months occurred in 18.5% with instrumentation (PLF) versus a substantially lower 5.6% for noninstrumented posterior fusions (PLF).^[14,16]

Several risk factors contribute to ASD following the application of instrumentation; fusion length (especially three or more levels), preoperative sagittal malalignment, facet injury/tropism, advanced age, increased body mass index (BMI), and preoperative documentation of cephalad degenerative disease (e.g., disc disease, stenosis).^[13,15,18,24,26] In addition, although instrumented fusions increased the fusion rate, this did not necessarily correlate with improved outcomes. Furthermore, dynamic stabilization techniques failed to protect patients from ASD.^[8,21]

INCIDENCE OF ADJACENT SEGMENT DISEASE FOLLOWING LUMBAR FUSIONS IN 135 CASES OR GREATER [TABLE 1]

Minimally invasive lumbar instrumented fusions: posterior lumbar interbody fusions and transforaminal lumbar interbody fusions: Impact of body mass index (BMI) on adjacent segment disease

In 2015, Ou *et al.* assessed whether BMI contributed to ASD following 190 lumbar fusions for degenerative

disease [Table 1].^[13] Thirteen (6.8%) patients developed ASD observed from 21 to 66 months postoperatively; 5 were sufficiently symptomatic to warrant secondary surgery. They concluded; increased BMI contributed to ASD, and documented that “any increase of one mean value in BMI would increase the ASD rate by 67.6%” (e.g., 11.9% of patients with BMI ≥25 kg/m were diagnosed as having ASD at the last follow-up).

Intraoperative and perioperative complications in minimally invasive transforaminal lumbar interbody fusion

Wong *et al.* reviewed intraoperative and perioperative complications for 513 consecutively performed MIS TLIF (cohort series) performed for lumbar degenerative disc disease over a 10-year interval [Table 1].^[21] These included initial or revision 1–2 level MI-TLIF. They noted a perioperative complication rate of 15.6% e.g., 2.3% instrumentation failure, durotomy 5.1% with an equal incidence for revision vs. multilevel surgery, medical infections 1.4%, and surgical infections 0.2%. Significantly, higher infection rates were found for revision MI-TLIF, and more complications were observed for multilevel procedures.

Long-term outcomes after noninstrumented lumbar arthrodesis

Santiago-Dieppa *et al.* looked at the frequency of ASD following noninstrumented lumbar fusions performed at one institution for degenerative disease over a 20-year period (median 92 months) [Table 1].^[19] A total of 376 patients averaged 61.1 years of age. Of

Table 1: Incidence of ASD* following lumbar fusion in 135 cases or greater

Author (reference) (year)	Number patients	Outcomes including ASD*	ASD* outcomes frequency other	Conclusions ASD instrumented fusions
Wong <i>et al.</i> ^[21] 2015	513 MIS ^ ^ TLIF***	Lumbar degenerative disc disease	Perioperative complications 15.6% Over a 10 years period	Complications 5.1% durotomy 1.4% medical infection 0.2% surgical infection 2.3% instrument failure
Ou <i>et al.</i> ^[13] 2015	190 patients Degenerative lumbar disease	ASD* 13 (6.8%) Interval 21-66 months 5 required surgery	> BMI ^ ^ ^ increased risk of ASD* One mean value of BMI ^ ^ ^ Increased ASD* by 67.6%	11.9% of patients BMI ^ ^ ^ ≥25 kg/m had ASD*
Santiago-Dieppa <i>et al.</i> ^[19] 2014	376 noninstrumented PLF ^ ^ ^ ^ Over 92 months Average age 61.1	Stenosis: 211 (56.1%) Back pain: 344 (91.5%) Radiculopathy: 304 (80.9%)	ASD* 18.35% (69 patients)	Reoperation (no better/worse): 30.59% (115)
Jalalpour <i>et al.</i> ^[5] 2015	135 total 96 disc disease 39 postdiscectomy Randomized TLIF*** 68 PLIF** 67 patients	Back pain 1 year Age 20-65 1-2 level disease Analysis VAS*****/ ODI*****	98% TLIF *** versus PLF**** less pain but not significantly better ODI scores versus PLF	2 years results: Less optimal outcomes of uninstrumented PLF explained by much higher reoperation rate

*ASD: Adjacent segment disease, **PLIF: Posterior lumbar interbody fusion, ***TLIF: Transforaminal lumbar interbody fusion, ^MIS: Minimally invasive surgery, ^BMI: Body mass index, ^^^PLF: Posterolateral fusions, ****VAS: Visual analog scale, *****ODI: Oswestry disability index

these, 211 (56.1%) exhibited multilevel spinal stenosis with claudication; ASD was present in 18.35% (69 patients), and re-operations (e.g., due to failure to improvement/worsening) were required in 30.59% (115 of patients) patients. The authors concluded, due to the high reoperation rate, that more instrumentation was warranted.

Randomized controlled trial comparing instrumented transforaminal lumbar interbody fusions versus noninstrumented posterolateral lumbar fusion for the treatment of degenerative lumbar spine disease

Jalalpour *et al.* compared the 2-year clinical outcomes of TLIF (68 patients: pedicle titanium screw fixation and a porous tantalum interbody spacer with interbody and posterolateral autograft) versus noninstrumented PLF (67 patients; used autograft) procedures for managing chronic low back pain in 135 patients with degenerative disc disease ($n = 96$) or postdiscectomy syndrome ($n = 39$) [Table 1].^[5] Patients had to exhibit back pain for over 1 year with/without leg pain, and had 1–2 level pathology; those with prior surgery other than for discectomy were excluded, along with those exhibiting a free disc fragment. The two treatment groups improved significantly over the 2 year follow-up period. They found that TLIF versus PLF patients had less pain but not significantly better Oswestry Disability Index (ODI) scores. However, the authors still concluded: “The less optimal outcome after uninstrumented PLF may be explained by the much higher reoperation rate.”

INCIDENCE OF ADJACENT SEGMENT DISEASE FOLLOWING LUMBAR SPINE INSTRUMENTATION IN UP TO 101 CASES [TABLE 2]

Efficacy of posterior lumbar interbody fusion plus cephalad decompression for symptomatic adjacent segment disease

Hikata *et al.* noted that for 54 patients undergoing L4–L5 PLIF (performed for degenerative spondylolisthesis [DS]), fusion would potentially increase mechanical stress and degenerative changes at the adjacent L3–L4 level [Table 2].^[3] For a subset of 37 symptomatic patients, they simultaneously performed a L4–L5 PLIF and prophylactically decompressed the L3–L4 level (without fusion). At an average of 2 years later, although 31 (57.4%) patients demonstrated radiographic ASD, only 7 (13.0%) had symptomatic ASD; 6 had undergone prophylactic decompressions (16.2%), whereas 1 had only a L4–L5 PLIF (5.9%). In short, prophylactic cephalad decompression failed to reduce the frequency of 2-year postoperative symptomatic ASD.

Risk factors for adjacent segment disease after lumbar fusion

Masevnin *et al.* studied the frequency of ASD in 120 patients who had 360° lumbar fusions (2007–2012) [Table 2].^[9] For 60 patients undergoing 3 or more level fusions, ASD was found in 19 patients at 1 year and in 31 patients after 3 years. For the other 60 undergoing only 1–2 level fusions, 10 developed ASD at 1 postoperative year, while 14 had ASD at 3 postoperative years. They

Table 2: Incidence of ASD* following lumbar spine instrumentation in up to 101 cases

Author (reference) (year)	Number patients	Outcomes including ASD*	ASD* outcomes frequency other	Conclusions ASD* instrumented fusions
Hikata <i>et al.</i> ^[3] 2014	54 17 L45 PLIF** alone 37 L45 PLIF**/L34 decompression	Outcomes 2 postoperative years 57.4% radiographic ASD	Outcomes 2 postoperative years 7 (13.0%) symptomatic ASD	6 PLIF** with decompressions 1 PLIF** alone Decompressions not reduce ASD
Nakashima <i>et al.</i> ^[10] 2015	101 PLIF**	9.9% (10) reoperations for ASD* 80% at 5 years	Cranial ASD* 10 years MR 62 disc 25 stenosis	Caudal ASD 10 years MR 68 disc 12 stenosis
Radcliff <i>et al.</i> ^[16] 2014	53 (1 year) 1-2 level ALIF ^ Followed by 23 MIS PI**** 30 open PI****	23 MIS PI**** 7 (30%) ASD*	30 open PI**** 9 (30%) ASD*	
Yee ^[24] 2014	68 52 MIS ^ ^ TLIF*** versus 16 open TLIF***	ASD* 7 (10%)	ASD* frequency 4 MMI TLIF*** 3 open TLIF***	Not significantly different ASD* For two groups
Masevnin <i>et al.</i> ^[9] 2015	120 360 fusion TLIF***/PLIF**	Levels of fusion >3-60 patients 1-2-60 patients	>3 level fusions 19 (15.8%) ASD*: 1 year 31 (25.8%) ASD*: 3 years	1-2 level fusion 10 ASD* 1 year 14 at 3 years

*ASD: Adjacent segment disease, **PLIF: Posterior lumbar interbody fusion, ***TLIF: Transforaminal lumbar interbody fusion, ****PI: Posterior instrumentation, ^ALIF: Anterior lumbar interbody fusion, ^^MIS: Minimally invasive surgery, MR: Magnetic resonance

concluded; >3 or greater segment fusions contributed to greater overloading of adjacent segments. Alternatively, for those undergoing short 1–2 level fusions, preoperative magnetic resonance (MR) findings of ASD fundamentally determined the extent of postoperative ASD.

Adjacent segment disease after posterior lumbar interbody fusion with 10 years of follow-up

In 2015, Nakashima *et al.* followed 101 patients undergoing PLIF who were followed for a minimum of 10 years; they utilized X-ray and MR studies to evaluate ASD at 2, 5, and 10 years postoperatively [Table 2].^[10] Cranial versus caudal ASD, respectively, documented disc degeneration (62 cranial and 68 cases caudal) and stenosis (25 cranial and 12 cases caudal) on MR imaging scans 10 years postoperatively. ASD reoperations were required in a total of 10 (9.9%) patients, 80% of which were performed within 5 postoperative years.

Rate of adjacent segment disease after percutaneous minimally invasive surgery versus open fusion

When Radcliff *et al.* looked at the frequency of ASD following one or two level anterior lumbar interbody fusions (ALIF) followed by posterior open versus posterior MI lumbar instrumentation, they found that both types of posterior fusions contributed to a 30% incidence of ASD [Table 2].^[16] The study involved a total of 53 patients. Of the 23 having MIS posterior instrumented fusions, 7 (30%) developed ASD. Of the 30 undergoing open posterior instrumented fusion, 9 (30%) developed ASD (30%). In summary, the incidence of ASD was the same when ALIF was followed

by MIS/percutaneous versus open posterior instrumented fusions.

Comparison of adjacent segment disease after minimally invasive transforaminal lumbar interbody fusion versus open transforaminal lumbar interbody fusion

In a retrospective cohort study of 68 patients, Yee *et al.* (2014) evaluated the frequency of ASD following MI TLIF (52 patients) versus open TLIF (16 patients; slightly older); all patients were followed for a minimum of 6 months looking for the onset of symptomatic ASD [Table 2].^[24] ASD was observed in 7 (10%) patients who averaged 62 years of age (3 male, 4 female); 4 had MI TLIF, while 3 had open TLIF. Notably, the frequency of ASD did not significantly differ between the two groups.

DEGENERATIVE SPONDYLOLISTHESIS: CONCLUSIONS REGARDING ADJACENT SEGMENT DISEASE AND OTHER FACTORS [TABLE 3]

Risk factors for adjacent segment disease after posterior lumbar interbody fusion for degenerative spondylolisthesis

Over a 2-year period, Okuda *et al.* evaluated the frequency of ASD for 87 patients undergoing PLIF at the L4–L5 level for DS [Table 3].^[11] They studied risk factors that could accelerate cephalad ASD following L4–L5 PLIF. They broke down progression of ASD at the L3–L4 level into three groups defined by the extent of increased disc narrowing and olisthesis: Group 1–58 (67%) patients

Table 3: DS*: Conclusions regarding ASD and other factors**

Author (reference) (year)	Number patients with DS** surgery	ASD** incidence progression other variables	ASD**	Conclusions regarding ASD**
Okuda <i>et al.</i> ^[11] 2004	87 PLIF*** open DS*	ASD** L34 Group 1 No progression 58 (67%)	ASD** L34 Group 2 Asymptomatic progression 25 (29%)	ASD** L34 Group 3 4 (4%) progression more surgery
Sakaura <i>et al.</i> ^[18] 2013	40 PLIF*** for Grade I DS*	Followed 4 or > years 4 (10%) ASD** at the cephalad level	Risk factors for ASD** Age, sex Fusion level Lordosis Prior angulation Facet tropism	Most critical risk factor: Malalignment
Zencica <i>et al.</i> ^[26] 2010	91 PLIF*** for DS* 1990-2001	Average age 40.8 Followed average 6.1 years	Symptomatic ASD** 10 (11%) for patients followed average 3.8 years	ASD** with instability 4 above fusion Degeneration with fusion 4 above 3 below
Yugue ^[25] 2015	161 patients L4-L5 DS* Preoperative Myelo-CT documented ASD**	22 patients (13.7%) required additional cephalad surgery	Myelo-CT preoperatively showed ≥47% incidence of cephalad stenosis	Factors contributing to ASD** Prior stenosis >Facet tropism >BMI****

*DS: Degenerative spondylolisthesis, **ASD: Adjacent segment disease, ***PLIF: Posterior lumbar interbody fusion, ****BMI: Body mass index

showed no progression, Group 2–25 (29%) patients had asymptomatic progression, and Group 3–4 (4%) patients had progression warranting further surgery to address neurologic worsening. They failed to discover clear-cut risk factors that could help predict these changes.

Symptomatic adjacent segment disease after posterior lumbar interbody fusion for adult low-grade isthmic spondylolisthesis

Over at least a 4-year period, Sakaura *et al.* found the frequency of symptomatic ASD to be 10% (4 patients) following 40 PLIF (with pedicle screws) performed for adult low-grade isthmic spondylolisthesis (IS) [Table 3].^[18] They identified the following risk factors as contributors to ASD: age, sex, fusion level, lordosis, facet tropism, and most importantly, the prior laminar inclination angle at the cranial level above the fusion.

Adjacent segment disease after lumbosacral fusion for spondylolisthesis

In 2010, Zencica *et al.* evaluated the frequency of ASD (retrospective, X-ray study) following 91 PLIF (transpedicular fixation) performed in patients with spondylolisthesis (e.g., isthmic [70 patients], degenerative [14 patients], or dysplastic [7 patients] spondylolisthesis at the L4–L5 or L5/S1 levels); patients were followed an average of 6.1 years [Table 3].^[26] Symptomatic ASD was observed in 10 (11%) patients (over 3.8 years); 4 patients were unstable above the fusion, while 7 showed degeneration above (4 patients) or below the fusion (3 patients).

Cephalad stenosis requiring more surgery following L4–L5 fusion for degenerative spondylolisthesis

Yugue *et al.* (2015) looked at the frequency and predisposing elements contributing to ASD following 161 single level fusions where patients' preoperative Myelo-CT studies showed preexisting cephalad stenosis [Table 3].^[25] They noted that 22 patients (13.7%) required additional cephalad surgery, and that in $\geq 47\%$ of cases preoperative Myelo-CT studies had documented stenosis at these levels. Additional risk factors for ASD included; greater facet tropism and a high BMI.

REVIEW ARTICLES ON ADJACENT SEGMENT DISEASE FOLLOWING FUSIONS AND OTHER FACTORS [TABLE 4]

Adjacent segment disease after lumbar or lumbosacral instrumented fusion

In 2004, Park *et al.* evaluated the frequency of pathological changes (e.g., motion, stenosis, and disc degeneration) adjacent to the levels of prior instrumented lumbar fusions [Table 4].^[14] They summarized the biomechanical changes that occur; increased intradiscal

pressure, increased facet loading, increased mobility, and progressive age-related degenerative changes over. The frequency of ASD radiographic degenerative over an average 36–369 postoperative months ranged from 5.2% to 100%, while that of symptomatic ASD varied from 5.2% to 18.5% over 44.8–164 postoperative months. Alternatively, for those receiving noninstrumented fusions, the risk of developing ASD was substantially lower (5.6% at 164 postoperative months). Risk factors that contributed to symptomatic ASD included; “instrumentation, fusion length, sagittal malalignment, facet injury, age, and preexisting degenerative changes.” Secondary surgery typically required the extension of the decompression and fusion; the quality of outcomes associated with these procedures were considered modest.

Lumbar spinal stenosis: who should be fused?

In 2014, Omid-Kashani *et al.*, when evaluating lumbar spinal stenosis, asked who should be fused? For patients with radiculopathy but without instability, decompression alone should suffice [Table 4].^[12] Alternatively, indications for fusion often included; “failed back surgery syndrome (revision surgery), degenerative instability, deformity, symptomatic spondylolysis, refractory degenerative disc disease, and adjacent segment disease.” They found that lumbar instrumented fusions did not necessarily contribute/correlate with improved outcomes.

Adjacent segment disease in the lumbar spine following instrumented fusion

Radcliff *et al.* reviewed the literature in MEDLINE regarding the frequency of ASD adjacent to a prior lumbar fusion [Table 4].^[15] They asked whether the development of ASD was attributable to altered biomechanics due to the fusion itself, or a result of natural disease progression. They observed the rate of ASD adjacent to an instrumented fusion was 2–3% per year, and highly correlated with the performance of a laminectomy adjacent to the fusion level, or the presence of sagittal imbalance.

Fusion for low-grade adult isthmic spondylolisthesis

In 2006, Jacobs *et al.* evaluated which fusion method resulted in better outcomes (clinical/radiographic) for patients with low-grade IS [Table 4].^[4] They utilized multiple databases (MEDLINE, EMBASE, Current Contents, and Cochrane Databases) along with consulting other selected articles including randomized controlled trials (RCTs). They utilized 29 studies out of 684 references utilizing the different techniques of performing PLF. They found; PLF was superior to nonoperative treatment (exercise), results of PLF were comparable to circumferential fusions, and three studies showed there were no additional benefits for using instrumentation. Operative results for PLF also revealed

Table 4: Review articles on ASD ^ and other factors

Author (reference) (year)	Review study	Outcomes fusion rates other	ASD fusion rates outcomes other	Conclusions
Omidi-Kashani <i>et al.</i> [12] 2014	Review study	Instrumentation improves the fusion rate		Fusion not correlated with better outcomes
Radcliff <i>et al.</i> [15] 2013	Review medline Literature	ASD* following lumbar fusion 2-3%/year	ASD* more after Laminectomy next to fusion	Loss of sagittal imbalance contributed to ASD*
Jacobs <i>et al.</i> [4] 2006	Review 29 studies IS ^ ^ ^ ^ PLF** superior to no surgery PLF** results similar to 360 procedures	PLF** Good/Exc. ^ 60-98% Fusion 81-100% PLIF***/TLIF ^ ^ Good/Exc. ^ 45% Fusion 80-95%	ALIF****. Good/exc. 85-94% Fusion 47-90% No evidence instrumentation and/or decompression better for IS ^ ^ ^ ^	ASD* was not reported in any studies
Liu <i>et al.</i> [7] 2014	Meta-analysis 4 RCT***** 5 observational studies Spondylolisthesis	PLIF*** more effective than PLF** for > Satisfaction > Fusion < Reoperations		No significant differences Complication blood loss Operative times
Schroeder <i>et al.</i> [20]	Questionnaire 223 spine surgeons DS ^ ^ ^	53.2% recommended decompression alone for single level DS ^ ^ ^		Did not recommend PLIF*** or TLIF ^ ^ For single level DS ^ ^ ^
Ye [23] 2013	Meta-analysis DS ^ ^ ^	PLIF*** versus PLF** equal Pain relief Quality of life Fusion, infection	Same VAS and ODI scores	5 studies showed higher fusion rates with PLIF
Hart <i>et al.</i> [2] 2015	42 studies reviewed 10 years	35 RCT***** Degenerative disc disease only	4 RCT for DS ^ ^ ^ 4 RCT DS ^ ^ ^ and degenerative disc disease	Better results fusion for degenerative disc disease and/or DS ^ ^ ^
Park <i>et al.</i> [14] 2004	Review article TLIF ^ ^ ^ ^ PLIF ^ Risk factors ASD* Instruments Fusion length	Risk factors Malalignment Facet injury Age Prior disease	ASD* 44.8 months 5.2% 164 months 18.5%	ASD* with instrumentation 12.2-18.5% versus no fusion 5.2-5.6%

*ASD: Adjacent segment disease, **PLF: Posterolateral fusion, ***PLIF: Posterior lumbar interbody fusion, ^Exc.: Excellent, ^^TLIF: Transforaminal lumbar interbody fusion, ****ALIF: Anterior lumbar interbody fusion, *****RCT: Randomized controlled trials, ^^DS: Degenerative spondylolisthesis, ^^AIS: Isthmic spondylolisthesis, VAS: Visual analog scale, ODI: Oswestry disability index

no impact for the different types of decompression, alternative instrumentation, or bone graft substitutes utilized. They evaluated 21 case series consisting of 24 patient groups. PLF in 15 studies showed good/excellent outcomes in 60–98% of cases, with fusion occurring in from 81% to 100% of cases. ALIF (four groups) showed good/excellent outcomes in 85 to 94% of cases; they fused 47–90% of the time. PLIF/TLIF fusions (two groups) showed, good or excellent outcomes in 45% of cases, and fusions were confirmed 80% to 95% of the time. Of interest, 18 studies reported various complications (e.g., neurological, instrument failure, and infections), and the lack of superiority for PLF, PLIF, and ALIF fusion techniques. Furthermore, no studies documented the superiority of utilizing instrumentation versus decompressions alone for managing spondylolisthesis.

Meta-analysis comparing posterior lumbar interbody fusion versus posterolateral lumbar fusion using transpedicular screw fixation for isthmic spondylolisthesis

Ye *et al.* (2013) performed a comparison between PLIF versus PLF for managing IS, looking at pain relief, quality of life, fusion, and infection rates [Table 4]. [23] Utilizing visual analog scales and ODI scores, both groups demonstrated comparable relief of pain and disability, respectively. Of interest, 5 studies showed higher fusion rates utilizing PLIF.

Evaluation of lumbar fusion over the past 10 years: A systematic review

In 2015, Hart *et al.* looked at 42 RCTs assessing the quality of evidence for lumbar fusions addressing degenerative disc disease (35 RCTs), DS (4 RCTs), and 3 RCTs with

both of the former over the last 10 years [Table 4].^[2] They excluded studies using bone morphogenetic protein-2, other bone graft substitutes, revision surgery, and/or low-quality studies. They concluded; more and better RCT studies increasingly utilized patient-based outcomes to document the superiority of fusion for treating degenerative disc disease and/or DS.

Rationale for the surgical treatment of lumbar degenerative spondylolisthesis

Schroeder *et al.* evaluated the management of lumbar DS, by looking at multiple variables: age, dynamic instability, and outcomes related to surgeon-related factors [Table 4].^[20] They noted that typically DS is managed with decompression/fusion, but in some cases, decompression alone suffices. This study surveyed 223 members of the Lumbar Spine Research Society and AO Spine; in older patients, 53.2% of surgeons would recommend, for one level DS, decompressions alone rather than TLIF/PLIF. Many of us would agree with this decision, particularly, since, many of these patients are osteoporotic with multiple added comorbidity risk factors (e.g., diabetes, hypertension, and coronary artery disease), often warranting anti-platelet aggregants or even anticoagulants.

LUMBAR INTERBODY FUSION VERSUS POSTEROLATERAL LUMBAR FUSION FOR LUMBAR SPONDYLOLISTHESIS; META-ANALYSIS

In 2014, in a meta-analysis of the literature (four randomized controlled and five comparative observational studies), Liu *et al.* compared the efficacy of PLIF versus PLF for managing lumbar spondylolisthesis [Table 4].^[7] PLIF was more effective than PLF for attaining greater clinical satisfaction, higher fusion rates, and lower

reoperation rates. Nevertheless, there were no significant differences in the complication rates, estimated blood loss, and operative times.

ADJACENT SEGMENT DISEASE LITERATURE REVIEW OF INSTRUMENTED CERVICAL FUSIONS

In 2014, Saavedra-Pozo *et al.* reviewed the PubMed literature regarding ASD looking at different cervical spine fusion strategies (e.g., instrumented, dynamic, etc.).^[17] Out of 850 articles, 41 articles were chosen; ASD in the cervical spine occurred in up to 3% of cases and did not reflect differences in fusion versus arthroplasty. Alternatively, ASD in the lumbar spine varied from 2% to 14%, and in the lumbar region, risk factors contributing to ASD in patients with degenerative disease included damage to the posterior ligamentous complex and/or sagittal imbalance. Notably, ASD was not due only to motion at the segment adjacent to a fusion.

DYNAMIC MODES OF STABILIZATION ADDRESSING ADJACENT SEGMENT DISEASE: DYNAMIC DEVICES RESULT IN COMPARABLE OUTCOMES [TABLE 5]

Short-term outcome of posterior lumbar dynamic stabilization with dynamic stabilization system

In 2014, Yang *et al.* noted that laminectomy accompanied by lumbar instrumented fusion for degenerative disease too frequently correlated with complications that included; “donor site pain, pseudoarthrosis, nonunion, screw loosening, instrumentation failure, infection, ASD, and degeneration” [Table 5].^[22] They proposed utilizing a neutralization system-dynamic stabilization system (DYNESYS) that utilized pedicle screws, polyethylene

Table 5: Dynamic modes of stabilization addressing ASD ^ ^ : Dynamic devices result in comparable outcomes

Author (reference) (year)	Number patients undergoing dynamic fusion	Systems and fusions	Outcomes	Conclusions
Yang <i>et al.</i> ^[22] 2014	75 patients 2 years 30 DYNESYS**** (average age 55.96) 45 PLIF ^ (average age 54.69)	Two levels 29 DYNESYS**** 39 PLIF ^ Three levels 1 DYNESYS 6 PLIF ^	Claims better outcomes ODI**, VAS* for DSYNESYS**** versus PLIF ^	Comparable percentage of ASD ^ ^ Comparable range of motion Comparable ASD disc degeneration
Lu <i>et al.</i> ^[8] 2015	91 PLIF ^ 1 level - L4-S1 2 level - L3-S1 4 level - L2-S1 Group A: PLIF ^ only 42 patients ASD ^ ^ 20 (48%) but only 3 symptomatic requiring reoperations	Group B IPD/DIAM with PLIF Proximal level 49 cases ASD 3 (6%) 1 symptomatic; reoperation Flexion/extension 35 mobility 35 14 restricted/lost	100% fusion with PLIF ^ both series After 24 months and after reoperations results were comparable on VAS and ODI	IPD ^ ^ ^/DIAM*** none developed new proximal ASD ^ ^

*VAS: Visual analog scale, **ODI: Oswestry disability index, ^PLIF: Posterior lumbar interbody fusion, ^^ASD: Adjacent segment disease, ^^IPD: Interspinous process device, ***DIAM: Name of IPD, ****DYNESYS: Dynamic stabilization system, DIAM: Device for intervertebral assisted motion

terephthalate cords, and polycarbonate urethane spacers to stabilize the motion segment to avoid/limit ASD (e.g., preserving adjacent segment motion). They evaluated 75 consecutive patients who underwent, over average 2 year periods, either 30 DYNESYS fusions (29 two levels; average age 55.96), or 45 PLIF (39 two levels average age 54.69). They claimed the DYNESYS group had shorter operation times (141.06 ± 11.36 min vs. 176.98 ± 6.72 min, $P < 0.001$) and less intraoperative blood loss (386.76 ± 19.44 ml vs. 430.11 ± 24.72 ml, $P < 0.001$). The bottom line, however, was that both systems produced similar changes in the range of motion (ROM) at adjacent levels and comparable degrees of disc degeneration. In short, there was no “significant advantages to motion preservation at adjacent segments, to avoid the degeneration of adjacent intervertebral disc.” Essentially, this system was not really a viable alternative to routine fusion, and likely over the long-term, the materials utilized in the fusion construct would fail. However, the follow-up for this study was not yet long enough to document those future failures.

Reduction in adjacent segment disease after multilevel posterior lumbar interbody fusion with/without addition of interbody fusion device proximal to posterior lumbar interbody fusion

In 2015, Lu *et al.* observed that multilevel lumbar fusions increased the risk of developing ASD [Table 5]. In this series, 91 patients underwent 2–4 level PLIF [Table 2]: Group A patients received a PLIF alone (42 cases), while Group B patients had the PLIF and, at the adjacent level, underwent placement of an interspinous process device (IPD) for Intervertebral Assisted Motion (49 patients).^[8] They reported that all PLIF solidly fused; had they utilized computed tomography in addition to X-rays alone, confirmation of this 100% fusion rate would have been unlikely. In addition, they noted on radiographs that ASD occurred in 20 (48%) patients from Group A (only 3 were symptomatic requiring second surgery), but only 3

(6%) had ASD from Group B (only 1 was symptomatic requiring secondary surgery). At final follow-up (approximately 2 years later), after reoperations had been performed to treat symptomatic ASD, no significant differences in outcomes were found for the two groups. Of interest, no patients with IPD developed further cephalad ASD. This study largely demonstrated that the implantation of IPD cephalad to an instrumented fusion was not “symptomatically” useful. Furthermore, these devices carry their own high failure rates (e.g., extrusion, spinous process fracture, CSF leaks, intrusion into the spinal canal, and disruption of the cephalad ligament/spinous process complex/motion segment plus other complications (e.g., epidural hematomas, infections, etc.).

BIODYNAMICS OF ADJACENT SPINAL DISEASE [TABLE 6]

Biodynamics of single-level instrumented lumbar laminectomy on adjacent segment disease biomechanics

In 2015, Bisschop *et al.* studied the ROM and stiffness of adjacent lumbar spinal segments along with ASD following laminectomy and fusion. Utilizing 12 human lumbar cadaveric spines, a laminectomy at L2 or at L4 was followed by posterior instrumentation.^[1] They studied; ROM and stiffness utilizing X-rays (e.g., in flexion and extension [FE], lateral bending [LB], and axial rotation [AR]). Postlaminectomy ROM increased (+19.4%), and stiffness decreased (–18.0%) in AR, but the ROM in AR of the adjacent segments increased (+11.0%). With instrumentation, the ROM at the fused segment decreased on FE (–74.3%), LB (–71.6%), and AR (–59.8%); additionally, adjacent segment changes showed adjacent ROM was reduced (–12.9%). In summary, the authors concluded that biomechanical data could not explain ASD.

Table 6: Biodynamics of ASD ^ ^

Author (reference) (year)	Biomechanics study designs	Levels of study	Range of motion ROM* using dynamic systems	Biomechanical findings conclusions
Bisschop <i>et al.</i> ^[1] 2015	Studied ROM* and stiffness on ASD ^ ^ following laminectomy and fusion Cadaveric 12 human lumbar spine	L2 or L4 Laminectomy Instrumented fusion	Laminectomy ROM* increased +19.4% Stiffness –18% AR** ROM* adjacent segments increased +11.0%	Fusion ROM* decreased FE ^ –74.3% LB*** decreased –71.6% AR** –59.8% Adjacent segment; ROM* reduced –12.9%
Kyaw <i>et al.</i> ^[6] 2014	Biodynamic study Pedicle screw impact on ASD ^ ^ Cadaver 10 boars-lumbar spine L2-L5	Adjacent levels ROM* >20% Torque >3 times AR** >100% Maximal torque >6 times	ROM* adjacent segments significantly increased after pedicle screws fixation	ROM* of fused segments led to greater torque at adjacent levels Contributed to degenerative changes of disc and spondylolisthesis

*ROM: Range of motion, **AR: Axial rotation, ***LB: Lateral bending, ^FE: Flexion, ^^ASD: Adjacent segment disease

BIOMECHANICAL IMPACT OF PEDICLE SCREWS ON ADJACENT SEGMENT DISEASE

In 2014, Kyaw *et al.* utilizing 10 cadaveric boars spines at the L2–L5 levels, evaluated the biomechanical impact of pedicle screws on ASD in the lumbar spine.^[6] They concluded; marked mechanical stresses are placed upon segments adjacent to a fusion. They concluded; the loss of ROM of the fused segments led to greater torque applied to adjacent levels, and this then contributed to further degenerative changes in the disc as well as the progression of spondylolisthesis.

CONCLUSIONS

This review raises the issue of whether ASD could be substantially reduced by performing fewer lumbar instrumented fusions. ASD occurred in up to 30% of lumbar instrumented fusions whether performed open or minimally invasively, with or without DS accompanying stenosis.^[3,8-11,13,14,16,23,26] Park *et al.*, however, documented a substantial reduction of ASD 164 months following noninstrumented (5.6% ASD) vs. instrumented lumbar fusions (18.5% ASD).^[14] Certainly, in older osteoporotic patients with multiple accompanying comorbid factors (e.g., many requiring prophylactic anti-platelet aggregants including aspirin or anticoagulants), avoidance of instrumentation (e.g., TLIF, PLIF) and alternatively choosing noninstrumented PLF should be strongly considered.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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