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Review Article

Lower complication and reoperation rates for laminectomy rather than MI TLIF/other fusions for degenerative lumbar disease/spondylolisthesis: A review

Nancy E. Epstein[1,2]

[1]Professor of Clinical Neurosurgery, School of Medicine, University of State of New York at Stony Brook, [2]Chief of Neurosurgical Spine/Education, NYU Winthrop Hospital, Mineola, New York, USA

E-mail: *Nancy E. Epstein - nancy.epsteinmd@gmail.com
*Corresponding author

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Abstract

Background: Utilizing the spine literature, we compared the complication and reoperation rates for laminectomy alone vs. instrumented fusions including minimally invasive (MI) transforaminal lumbar interbody fusion (TLIF) for the surgical management of multilevel degenerative lumbar disease with/without degenerative spondylolisthesis (DS).

Methods: Epstein compared complication and reoperation rates over 2 years for 137 patients undergoing laminectomy alone undergoing 2-3 level (58 patients) and 4-6 level (79 patients) Procedures for lumbar stenosis with/without DS. Results showed no new postoperative neurological deficits, no infections, no surgery for adjacent segment disease (ASD) , 4 patients (2.9%) who developed intraoperative cerebrospinal fluid (CSF) fistulas, no readmissions, and just 1 reopereation for a (postoperative day 7). These rates were compared to other literature for lumbar laminectomies vs. fusions (e.g. particularly MI TLIF) addressing pathology comparable to that listed above.

Results: Some studies in the literature revealed an average 4.8% complication rate for laminectomy alone vs. 8.3% for decompressions/fusion; at 5 postoperative years, reoperation rates were 10.6% vs. 18.4%, respectively. Specifically, the MI TLIF literature complication rates ranged from 7.7% to 23.0% and included up to an 8.3% incidence of wound infections, 6.1% durotomies, 9.7% permanent neurological deficits, and 20.2% incidence of new sensory deficits. Reoperation rates (1.6–6%) for MI TLIF addressed instrumentation failure (2.3%), cage migration (1.26–2.4%), cage extrusions (0.8%), and misplaced screws (1.6%). The learning curve (e.g. number of cases required by a surgeon to become proficient) for MI TLIF was the first 33-44 cases. Furthermore, hospital costs for lumbar fusions were 2.6 fold

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greater than those for laminectomy alone, with overall neurosurgeon reimbursement quoted in one study as high as $142,075 per year.

Conclusions: The spinal literature revealed lower complication and reoperation rates for lumbar laminectomy alone vs. higher rates for instrumented fusion, including MI TLIF, for degenerative lumbar disease with/without DS.

Key Words: Complication rates, fusions, laminectomy alone, minimally invasive, reoperation rates, transforaminal lumbar interbody fusion

INTRODUCTION

When reviewing the literature, we asked whether lower complication and reoperation rates would be associated with performing multilevel laminectomy alone vs. fusions [e.g., predominantly minimally invasive (MI) transforaminal lumbar interbody fusion (TLIF)] for degenerative lumbar disease with/without degenerative spondylolisthesis (DS) [Tables 1-6]. In a personal consecutive cohort series of 137 patients undergoing multilevel laminectomies without fusions, at 2 postoperative years, there were no new neurological deficits, no infections, 4 (2.9%) intraoperative cerebrospinal fluid (CSF) fistulas (e.g. only in for those undergoing 4-6 level lamienctomies), and just 1 (0.7%) reoperation (sterile seroma at 7 postoperative days without readmission) [Table 2].[16] In a review of 37 studies from PubMed/Medline involving 1156 patients with lumbar spinal stenosis and stable low-grade 1–II DS (1983–2015) undergoing decompressions alone, Scholler *et al*. documented reoperation rates of 16.3% for OL (open laminectomy: 19 studies) vs. 5.8% for MIL (minimally invasive laminotomy: 18 studies).[36] In another study (2013) addressing degenerative lumbar disease/DS, Lad *et al*. showed that the complication rate for laminectomy alone was 4.8% vs. 8.3% for instrumented fusions; 5 years later, the reoperation rate was 10.6% without vs. 18.4% with spinal instrumentation [Table 1].[21] Other studies documented a 5.6% incidence of adjacent segment disease (ASD) following lumbar decompressions with noninstrumented fusions vs. 18.5% for decompressions with spinal instrumentation.[11,13] The MI TLIF literature documented a 7.7–19.2% complication rate for degenerative lumbar disease, that increased to 13–23.04% when combined with degenerative spondylolisthesis (DS); complications included 0.2–8.3% wound infections, 3.9–6.1% durotomies, 0.2–9.7% permanent neurological deficits, and 20.2% new sensory deficits [Tables 3-5]. Reoperations rates for MI TLIF ranged from 1.6-6% and addressed instrumentation failure (2.3%), cage migration (1.3–2.4%), cage extrusions (0.8%), and misplaced screws (1.6%) [Table 3 and 5].[3,23,31,40] Four studies documented the "learning curve" for safely/effectively performing MI TLIF required from 33-44 of the initial cases vs. Ahn *et al*. finding of no such learning curve (0 cases) for becoming proficient in performing MI laminotomy alone (0%) [Table 6].[1,22,27,31,37] In addition, not only were the costs for fusions 2.6 fold greater than those for laminectomy alone, but physician reimbursement rates were also higher with fusions (e.g., TLIF/MI TLIF/PLIF/others average $142,075/year).[25,42] Here, we predomiantly reviewed the literature regarding complication and reoperation rates for performing laminectomy alone vs. MI TLIF. In particular, we asked whether for comparable degenerative lumbar disease/DS, whether the added morbidity of MI TLIF fusion was and is acceptable.

Trends toward more laminectomies/fusions vs. laminectomies alone for degenerative lumbar disease with/without degenerative spondylolisthesis (DS)

For lumbar degenerative disease with/without DS, several studies documented the increasing trend toward utilizing not only laminectomy for decompression but also adding instrumented fusions [Table 1].[2,29] Utilizing the Nationwide Inpatient Sample, Bae *et al*. (2013) examined the national trends for managing lumbar spinal stenosis (LSS) from 2004 to 2009 [Table 1].[2] The number of decompressions alone decreased from 58.5% to 49.2%, "simple fusions" (1–2 disc levels/single approach) increased from 21.5% to 31.2%, while the number of complex fusion (>2 disc levels/360 procedures) remained the same (6.7%). Of interest, the frequency with which bone morphogenetic protein (BMP)/INFUSE was used (largely "off-label" in the posterior lumbar spine) increased from 2004 to 2009, more than two fold (14.5% to 33.0% of fusions). There was also a 1.6 fold greater incidence of interbody fusions (28.5% to 45.1%). Notably, by 2009, 26.2% of patients with LSS without instability (without DS) were fused, while 82.7% of those with LSS/DS, and 67% of those with LSS/scoliosis had fusions. When Norton *et al*. (2015) evaluated 48,911 patients from the Nationwide Inpatient Sample Database (2001–2010) undergoing lumbar fusions for DS (237,383 procedures), more patients underwent posterolateral lumbar fusions (PLF), anterior lumbar interbody fusions (ALIF) with PLF, or ALIF alone; fewer had TLIF only or TLIF with PLF [Table 1].[29] Furthermore, PLF, typically performed in older patients, correlated with lower hospital charges, shorter length of stay (LOS), fewer complications, and reduced mortality

Table 1: Literature summarizing complications, reoperation rates, and incidence of adjacent segment disease utilizing laminectomy for degenerative lumbar disease vs. decompressions/fusions

Author (reference) year	# Patients # articles	Focus	Complications
Lad[21] 2013	16,556 markets can degenerative spondylolisthesis (DS) With/without fusion Complications reoperations 2000-2009	With fusion 8.3% complication rate (3 postoperative mos) 18.4% reoperation 5 yrs. later with fusion	Without fusion 4.8% complication rate (3 postoperative mos.) 10.6% reoperation 5 yrs. later no fusions
Bae[2] 2013	2004-2009 Nationwide Inpatient Sample: LSS-Lumbar Spinal Stenosis Laminectomy/diskect-omy LSS/ DS-Simple Fusion (1-2 discs) LSS/Scoliosis-Complex fusion (> 2 disc levels/360 Fusions)	Decompression alone<58.55 to 49.2% Simple fusions>21.5% to 31.2% Complex fusions same 6.7% vs. 6.7% Use of BMP Infuse 2X 14.5% vs. 33.0% Interbody devices>1.6 X >28.5% vs. 45.1%	In 2009 26.2% LSS Patients±Instability had fusions LSS/DS Fused: 82.7% LSS/Scoliosis 67.6% Fused
Patil[32] 2014	174 Patients MarketScan Database 2007-2009 12 Postoperative mos.	Laminectomy alone 9.2% Complication rate	Laminectomy alone 5.8% Reoperation Rate
Epstein[11] 2015	Instrumented fusions TLIF PLIF PLF	ASD MI TLIF up to 30% Add instrumentation- No improved outcomes	Non Instrumented Fusions ASD 5.6% vs. 18.5% ASD Instrumented Fusion
Norton[24] 2015	TLIF with Stenosis/DS 48,911 (237,383 procedures) Nationwide Inpatient Database 2001-2010 PLF; ALIF + PLF; TLIF + PLF; ALIF; TLIF	Trend 2001-2010: More PLF; ALIF ALIF+PLF Trend 2001-2010; Fewer TLIF or TLIF + PLF > Mortality With: PLF+TLIF or ALIF	<Mortality-PLF Fewer Complications PLF: <LOS, <Charges Older patients<Complications More Complications ALIF + PLF; ALIF TLIF + PLF; TLIF
Epstein[15] 2016	336 Patients Avg. 66.5 years old 4.7 Level LAM Avg. 1.4 Level Noninstrumented Fusions Followed avg. 7.1 yrs.	LSS/DS (Grade I 195; Grade II 67) Added pathology: 154 Lumbar Discs, 66 Synovial cysts	Reoperations 9 (2.7%)-Mostly ASD Average 6.3 yrs. postoperatively Second surgery; 4.8 level laminectomies average 1.1 level noninstrumented fusions
Epstein[13] 2016	Older Literature Increased risks of ASD with lumbar fusions	ASD up to 30% of instrumented cases ASD 5.6% Without Fusions ASD 18.5% with Instrumented Fusions.	More Cephalad vs. Caudad ASD More ASD with Instrumentation
Bydon[6] 2016	398 Patients Evaluated ASD After 1-2 Level Lumbar Laminectomy without fusion Degenerative disease Followed 1 yr.	ASD: Requiring Reoperation Above/ Below Original Laminectomy 10% ASD 1-Level 9% ASD 2-Level Laminectomy	Second surgery 95% laminectomy 26% discectomy 49% fusion Time to ASD: 4 yrs.
Scholler[36] 2017	Secondary Fusion After Open vs. MI Decompression Lumbar Stenosis/DS without fusion PubMed/Medline 37 Studies 1156 Patients 1983-2015	18 MI Unilateral Lamintomy (MIL) vs. 19 Open Laminectomy (OL) Studies Secondary fusion 12.8% OL 3.3% MIL Total reoperation rates 16.3% OL 5.8% MIL	Slip Progression 72% OL 72% 0% MIL Outcomes-Satisfactory 62.7% OL 76% MIL

LSS: Lumbar spinal stenosis, DS: Degenerative spondylolisthesis, ASD: Adjacent segment disease, TLIF: Transforaminal lumbar interbody fusion, PLIF: Posterior lumbar interbody fusion, MI: Minimally invasive, PLF: Posterolateral fusion, BMP: Bone morphogenetic protein, X, Times (e.g., 2X=2 fold), MIL: Minimally invasive unilateral lamintomy, OL: Open laminectomy, Mos: Months, LAM: Laminectomy, Avg: Average, yrs: Years

Table 2: Epstein series clinical data following 2-3 (58 patients) vs. 4-6 level (79 patients) lumbar laminectomies without fusions[16]

Data	58 Patients 2-3 Level Laminectomies	Patients 79 4-6 level Laminectomies
Average age	50.34	57.31
STDEV	13.14	10.0
Sex		
Males	29	43
Females	30	35
Levels of Surgery	Average 2.8 Levels	Average 5.0 Levels
2 Levels	12	0
3 Levels	46	0
4 Levels	0	27
5 Levels	0	28
6 Levels	0	24
Disc Herniations	52 Discs/48 Patients	45 Discs/39 Patients
L23	2	4
L34	3	8
L45	22	23
L5S1	25	10
Degenerative spondylolisthesis (DS)	1	26
Synovial Cysts	20 Patients	45 Patients
1 Levels	14	15
2 Levels	6	22
3 Levels	0	6
4 Levels	0	2
Prior Surgery	7 Patients	5 Patients
1	1	1
2	6	4
CSF Fistulas	0	4
L1-S1 St/Disc	0	1
L1-S1St/Syn Cyst^^	0	1
L3-S1 St/Syn Cyst^^	0	1
L2-S1St/SynCyst^^,** (2nd Surgery)	0	1**
Infections	0	0
New Neurological Deficits	0	0
Surgical Readmissions	0	0
Reoperations	0	1*

**Delay to postoperative day 7 (sterile seroma), BPH/Urinary Retention/Hypotension, Postoperative Seroma requiring secondary surgery, Syn Cyst ^^, Massive synovial cysts, DS: Degenerative spondylolisthesis, St: Stenosis, STDVE: Standard deviation, CSF: Cerebrospinal fluid

rates vs. higher morality rates seen for TLIF with PLF or ALIF alone.

Complication and reoperation rates For laminectomy vs. fusions for degenerative lumbar disease with or without degenerative spondylolisthesis (DS)

The surgical literature showed lower complication and/or reoperation rates utilizing decompressions alone vs. decompressions and fusions for degenerative lumbar disease with/without DS [Table 1].[21,32,36] When Lad *et al*. (2013) evaluated lumbar decompressions performed between 2000 and 2009 utilizing the MarketScan database (the Thomson Reuters MarketScan Commercial Claims and Encounters and the Medicare Supplemental and Coordination of Benefits database containing 16,556 patients with a primary diagnosis of lumbar spondylolisthesis), the complication rate at 3 postoperative months was 4.8% for laminectomy without fusion vs. 8.3% with fusion; 5 years postoperatively, the reoperation rate for those undergoing laminectomy alone was 10.6% vs. 18.4% for instrumented arthrodeses.[21] Patil *et al*. (2014) also utilized the MarketScan Database (2007–2009; 16,556 patients) to identify 174 patients with degenerative lumbar disease/with DS undergoing laminectomy alone; at 1 postoperative year, the complication rate was 9.2% and the reoperation rate was 5.8%.[32] When Scholler *et al*. (2017) summarized the reoperation rates for 1156 patients with lumbar stenosis with low grade I–II DS in 37 studies obtained from Medline/PubMed (1983–2015), the total reoperation rate was 16.3% for open laminectomy (OL) vs. 5.8% for minimally invasive laminotomy (MIL); secondary fusions were warranted in 12.8% following OL and 3.3% after MIL [Table 1].[36]

Less adjacent segment disease (ASD) for decompressions/noninstrumented fusions vs. instrumented fusions for degenerative lumbar disease/degenerative spondylolisthesis (DS)

Several articles documented a lower incidence of ASD following laminectomy/laminectomy with noninstrumented fusion vs. decompressions with instrumented lumbar fusions (ASD) [Table 1].[6,11,13,15] In two review articles (2015, 2016), Epstein documented, that over 13 years, there was a 5.6% incidence of ASD with noninstrumented lumbar fusions vs. an 18.5% rate of ASD with spinal instrumenttion.[11,13] Yet the performance of an instrumented fusion did not significantly improve outcomes vs. noninstrumented fusions.[11,13] Bydon *et al*. (2016) demonstrated that, for 398 patients undergoing laminectomies alone without fusions, there was a 10% incidence of ASD following 1-level decompressions and a 9% frequency of ASD after 2-level decompressions.[6] In a personal clinical series (2016) involving 336 multilevel lumbar laminectomies (average, 4.7 levels) with noninstrumented fusions (average, 1.4 levels) for patients averaging 66.5 years of age with Grade I DS (154 patients) or Grade II DS (66 patients), Epstein documented that 9 patients (2.7%) required reoperations performed an average of 6.3 years after the index surgery.[15] These procedures addressed ASD attributed to stenosis/instability with grade I DS (7 patients) or grade II DS (1 patient), new disc herniations (2 patients), and a synovial cyst (1 patient).

Table 3: Summary complications/reoperations for TLIF/MI TLIF 2008-2013

Author (Reference#) Year	Procedures	Overall	Morbidity
Wong[39] 2008	TLIF/PLIF Off-Label Complications due to BMP-/INFUSE	Ectopic Bone in Lumbar Canal (Heterotopic Ossification HO)	New Neurological Deficits Due to HO in spinal canal
Owens[30] 2010	204 TLIF with BMP/INFUSE 12 mos. Follow-up	30 Perioperative Complications 5 (15.6%) Due to BMP/INFUSE	Complications 1 Nonunion/osteolysis 2 HO 2 perineural cysts (1 revision interbody cage)
Mroz[26] 2010	TLIF/PLIF Morbidity Due to BMP/INFUSE	44% Cage resorption 25% Subsidence	27% Cage migration
Balseiro[4] 2010	TLIF Morbidity BMP/INFUSE	High concentration Violation end plates resulted in subchondral cysts	2 Cases: Osteolysis, Plate Defects
Mannion[24] 2010	4 MI PLIF and 32 MI TLIF Fusions HO Due to BMP INFUSE	Revisions more difficult with HO due to BMP/INFUSE	> HO >Difficult revision surgery
Epstein[8] 2011	BMP/INFUSE for PLIF and TLIF widely used "off-Label" Complications HO, Paralysis (Cord/root damage), dural tears	Complications Respiratory Dysfunction Sphincter Loss Inflammation Fetal Malformations Scar, Excess Bleeding, Death	BMP/INFUSE with PLIF and TLIF Multiple Complications
Hoy[18] 2013	51 TLIF vs. 47 PLF 2 year follow up Prospective Randomized 2003-2008	Operative Time and EBL Significantly Higher TLIF patients	Similar Outcomes Both Groups
Chrastil[7] 2013	17 Articles Complications BMP/INFUSE for TLIF/PLIF	Epidural/Foraminal HO Radiculitis Osteolysis	BMP/INFUSE Interbody Device Subsidence
Saetia[34] 2013	24 Lumbar stenosis/DS 12 MIS TLIF 12 Open TLIF MIS Restricts Vision	MIS Limits Exposure Major Complications 8.3% Both Groups	MIS Operative Field is Limited

EBL: Estimated blood loss, LOS: Length of stay, RCT: Randomized controlled trials, BMP: Bone morphogenetic protein, HO: Heterotopic ossification, PLIF: Posterior lumbar interbody fusion, TLIF: Transforaminal lumbar interbody fusion, MI/MIS: Minimally invasive, DT: Dural tears

Separate Epstein series showed reduced complication/reoperation rates with laminectomy alone without noninstrumented fusion for treating degenerative lumbar disease/degenerative spondylolisthesis (DS)

Epstein performed a prospective, consecutive cohort study regarding the efficacy of laminectomy alone for 137 patients with degenerative lumbar disease/with or without DS.[16] The study included 58 patients undergoing 2–3 level (average, 2.8 levels) and 79 patients undergoing 4–6 level (average, 5.0 level) laminectomies for stenosis with/wihtout DS [Table 2]. Patients in the two groups averaged 50.3 vs. 57.3 years of age, respectively, and underwent average 3.3 hour and 4.01 hour decompressive procedures. These operations additionally respectively addressed 52 vs. 45 discs, 20 vs. 45 single/multiple synovial cysts, and/or 1. vs. 26 instances of DS. Patients were respectively discharged an average of 2.4 and 3.3 days postoperatively. Over 2 postoperative years, none of the 137 patients developed new neurological deficits, there were no infections, 4 (2.9%) developed intraoperative CSF fistulas (e.g., all undergoing 4–6 level decompressions), there were no readmissions, and just 1 patient (0.7%) required a reoperation (e.g., 7 days postoperatively for a sterile seroma). Notably none developed ASD.

Complication rate of minimally invasive transforaminal lumbar interbody fusion (MI TLIF) for degenerative lumbar disease without degenerative spondylolisthesis (DS)

The overall complication rate for MI TLIF fusions addressing degenerative lumbar disease without DS ranged from 7.7% to 19.2% [Tables 3–5].[17,19,31,34,40] For 12 minimally invasive MI TLIF vs. 12 open TLIF, Saetia *et al*. (2013) noted an 8.3% complication rate in both groups (2008–2009) [Table 3].[34] Park *et al*. (2015) observed that, out of 124 MI TLIF, there was a 9% incidence of perioperative complications [Table 4].[31] For Giorgi *et al*. (2015), 7.7% of 182 MI TLIF developed postoperative complications.[17] Wong *et al*. (2015) observed a 15.6% complication rate out of 513 MI-TLIF.[40] In a meta-analysis of 54 studies involving

Table 4: Summary of complications/reoperations for TLIF/MI TLIF 2014-2015

Author (reference#) year	Procedures	Overall	Morbidity
Nixon[28] 2014	340 MI TLIF for Stenosis/DS (Grade I/II) 2002-2012	Average age 65.5 3 F; 1 M	1.2% (4 Cases) Bilateral Lower Extremity Weakness
Wang[38] 2014	204 MIS-TLIF Lumbar Instability/DS 2007-2012 1 mos. Follow-up Retrospective Cohort	Type II (23.04%) 7 (9.3%) Deficits: 68 transient (90.67%) 75 neurological deficits	68 (90.67%) Transient Neurological Deficit 7 (9.3%) Permanent Deficit Most Transient Sensory Deficits
Giorgi[17] 2015	182 MI TLIF 1 Year Morbidity Multicenter Study Average Age 58.9	Postoperative Complications rate 7.7% Fusion rate 72.6%	Same Outcomes With/Without Fusion
Park[31] 2015	124 TLIF MI TLIF 9% (11) Perioperative Complications Learning Curve 8 -First 1/3 of series (41 Patients) 3 -Last 2/3 series (83 Patients)	3 Temporary neuralgia 2 Deep Infections, 2 Screw misplacements 2 Cage migrations 1 Dural tear 1 Grafted extrusion	6% (7/124) Reoperations 2 Cage migration 2 Misplaced screws 1 Extruded graft 2 Infected cages)
Klingler[20] 2015	372 MIS TLIF (514 Levels): High rate dural tear (DT)	Complications 32 (6.2%) Accidental Durotomies (DT)	Durotomies Correlated with: Age >65 and Obesity
Wong[40] 2015	513 MI-TLIF Complication 10 years Lumbar Degenerative Disease.	Perioperative Complications 15.6% 1.4%/0.2 Infection (Medical/surgical)	Complications 2.3% Instrumentation failure
Joseph[19] 2015	9714 Patients 5454 MI TLIF (6040 levels fused) vs. 4260 LLIF (7190 levels fused) 54 Studies Reviewed	1045/5454 (19.2%) Complications MI TLIF 3.57% Intraoperative complications 1.63% Wound Complications	MI TLIF complications Sensory Loss 20 0.16% Temporary Neurological Deficits 2.22% Permanent Neurological Deficits 1.01%
Norton[29] 2015	48,911 patients (237,383) procedures DS Nationwide Inpatient Sample 2001-2010	PLF: Lower Mortality Shorter LOS Lower Costs<Complications	TLIF Higher Mortality Rates

DT: Dural tears, EBL: Estimated blood loss, LOS: Length of stay, RCT: Randomized controlled trials, BMP: Bone morphogenetic protein, HO: Heterotopic ossification, PLIF: Posterior lumbar interbody fusion, TLIF: Transforaminal lumbar interbody fusion, MI: Minimally invasive, LLIF: Extreme lateral interbody fusions

MI TLIF (5454 patients; 6040 levels fused), Joseph *et al.* (2015) observed a 19.2% (1045 patients) complication rate.[19] In summary, the complication rates for MI TLIF fusions performed for patients with degenerative lumbar disease without DS were high, ranging up to 19.2%.

Complication rate for minimally invasive transforaminal interbody lumbar fusion (MI TLIF) For degenerative lumbar disease with degenerative spondylolisthesis (DS)

The overall complication rate for MI TLIF addressing degenerative lumbar disease with DS ranged from 13% to 23.04% [Tables 4 and 5].[23,38] Wang *et al.* (2014) found that from 2007 to 2012, the perioperative complication rate for degenerative lumbar disease/DS directly related to 204 MI TLIF up to 1 month postoperatively was 23% (64/204 patients); these included 1 complication (54 patients), 2 complications (9 patients), and 3 complications (1 patients); these included 68 transient (90.67% of 75 total neurological complications), and 7 (.93%) permanent complications [Table 4].[38] Liu *et al.* (2016) found a 13% perioperative complication rate for degenerative disease/DS treated with TLIF (101 patients) [Table 5].[23] Here, the overall range of complications for MI TLIF performed for degenerative lumbar disease with DS ranged up to 23%.

Minimally invasive transforminal interbody lumbar fusion (MI TLIF)-related new postoperative neurological deficits

Permanent neurological deficits following MI TLIF occurred in 0.2–9.7% of patients [Tables 3-5].[3,12,14,19,23,28,31,38] In a series of 204 MI TLIF, out of 75 reported neurological complications, Wang *et al.* (2014) found 68 (90.67%) transient deficits, while 7 were permanent (9.3%) [Table 4].[38] In a study by Nixon *et al.* (2014), out of

Table 5: Summary of complications/reoperations for TLIF/MI TLIF 2016

Name [Reference] Year	# Patients	Findings	Complications
Zhang[41] 2016	TLIF vs. PLF for Stenosis/DS Meta-analysis	630 patients 325 TLIF 305 PLF TLIF did not increase the Fusion Rate vs. PLF	No Significant Differences in: Outcomes Reoperation Rates Complications Duration of Surgery EBL LOS
Bakhsheshian[3] 2016	513 MIS TLIF Graft Extrusion Rates 1-3 level MI TLIF Average 13.6 mos. Follow-Up	513 Patients 5 (0.97%) Cage migration Cost cage migration and reoperation $17,217	+2 (0.4%) Asymptomatic Cage migration 2 (0.4%) Neurological Deterioration 1 (0.2%) Epidural Hematoma
Epstein[14] 2016	More Nerve Root Injuries MIS Lumbar Surgery Most with XLIF/LLIF	Nerve Root Injuries 0.13 0.25% Laminectomy Alone/Diskectomy 0% Open Laminectomy Stenosis±Fusion 2% Open Laminectomy Stenosis/DS±Fusion	Root Injuries: MIS TLIF 2% MIS PLIF 7.8% ALIF 15.8% XLIF 23.8%
Epstein[12] 2016	Increased Risk Adjacent Segment Degeneration (ASD) -Instrumented Lumbar Fusions	18.5% ASD TLIF/PLIF	5.6% ASD Non Instrumented Fusions/Decompressions Alone
Liu[23] 2016	101 TLIF 125 PLIF DS	TLIF Complications 2 cases (1.9%) Root dysfunction 4 (3.9%) dural tears	TLIF Complications 2 (1.9%) reoperations 5 cases (5%) (Wound infections

DT: Dural tears, EBL: Estimated blood loss, LOS: Length of stay, RCT: Randomized controlled trials, BMP: Bone morphogenetic protein, HO: Heterotopic ossification, PLIF: Posterior lumbar interbody fusion, TLIF: Transforaminal lumbar interbody fusion, MI: Minimally invasive, LLIF: Extreme lateral lumbar fusions, XLIF: Extreme lateral lumbar fusions

340 MI TLIF (2002–2012) performed for degenerative lumbar disease/DS (Grade I/II olisthesis), 4 (1.2%) patients averaging 65.5 years of age developed new bilateral lower extremity weakness [Table 4].[28] Joseph *et al.* (2015) observed that, following 5454 MI TLIF (6040 levels fused), there was a 20.2% incidence of new postoperative sensory deficits; postoperative motor deficits were transient in another 2.2% of patients and permanent motor deficits for 1.0% of patients [Table 4].[19] Liu *et al.* (2016) observed 2 (1.9%) patients with new permanent postoperative root dysfunction following 101 TLIF (101 patients) [Table 5].[23] Bakhsheshian *et al.* (2016) observed 2 (0.4%) new instances of neurological deterioration in a series of 513 MI-TLIF [Table 5].[3] In 2016, Epstein (2016) in two studies reviewed the quoted the incidence of nerve root injuries occurring utilizing conventional open decompressive techniques, some with fusions vs. minimally invasive lumbar surgery (e.g., decompressions with MIS TLIF, PLIF, ALIF, and XLIF) [Tables 3, 5].[12,14] For open discectomy, the frequency of nerve root injury ranged up to 0.25%, for open laminectomy for stenosis with/without fusion it was 0%; while for open laminectomy for stenosis/degenerative spondylolisthesis with/without fusion it was 2%.[14] Alternatively, root injuries were reported in 2% of MI TLIF (e.g., still 8 times higher than that with open discectomy/decompression), 7.8% of MIS PLIF, 15.8% of ALIFs, and a 23.8% frequency for extreme lateral interbody fusions (XLIFs).[14] As the incidence of nerve root injuries was so high for XLIFs, the inherent safety/efficacy of this procedure was questioned.

Frequency of dural tears with minimally invasive transforminal interbody lumbar fusion

Dural tears occurred in 3.9–6.1% of the patients undergoing MI-TLIF [Tables 3-5].[20,23,40] Wong *et al.* (2015) found a 5.1% durotomy rate for 513 MI-TLIF.[40] Klingler *et al.* (2015) noted that for 372 MIS TLIF (514 levels) there were 32 durotomies (6.2%) that highly correlated with more advanced age (e.g., over 65) and obesity.[20] Liu *et al.* (2016) found 4 (3.9%) instances of dural tears out of 101 TLIF (101 patients).[23] In Epstein's series, of 137 laminectomies without attendant fusions, the frequency of dural tears was lower e.g. 4 (2.9%).[16] Therefore, the incidence of dural tears was lower in standard open laminectomies vs. TLIF/MI/MIS TLIF fusions.

Reoperation rates for minimally invasive transforminal interbody lumbar fusion (MI TLIF)

Reoperations, performed in between 1.6% of the patients following MI TLIF, were largely attributed to instrumentation failures [Tables 3-5].[3,23,31,40] In Park *et al.* (2015), for 124 MI TLIF, 6% (7/124) required additional surgery; these included 2 (1.6%) for cage migrations, 2 (1.6%) for misplaced screws, and 1 (0.8%) for an extruded graft bone fragment.[31] In a study by

Table 6: Learning curve for TLIF/MIS TLIF vs. MI laminectomy/diskectomy

Name [Reference] Year	# Patients	Findings	Complications
Payer[33] 2011	Comparison Benefits vs., Rusks MI Lumbar Surgery Steep learning curve Decompressions/Fusions	9 RCT's Medline/PubMed No clear benefit MI vs. Open procedures For lumbar disc-TLIF or PLIF	"Tendency for more safety in open procedures for lumbar disc TLIF or PLIF"
Silva[37] 2013)	Learning curve for 110 1-Level TLIF 18 2-level TLIF 40th case: Learning Curve 90%	Overall complications 12.67% 5.32% Dural tear 90% milestone 20.51% Complications	90% Milestone By 40th Case
Lee[22] 2014	Learning Curve for MIS TLIF 2005-2009 90 MIS-TLIF Single Surgeon	Estimated 44 cases Asymptote Learning Curve Cases 45-90 (Latter) < Complications<OR Time, < Radiation<Postop pain, < Neurogenic symptoms	First 44 cases; 3 complications 1 durotomy 2 cage migration Latter 45-90 Cases 1 Asymptomatic Cage Migration
Nandyala[27] 2014)	Learning Curve 65 MIS TLIF Consecutive Cases One Surgeon Minimum 1 year Follow-up 90% Learning Curve 40th Case	First 33 Patients Longer OR time>EBL, > Longer surgery Complications 2 Pseudarthrosis 2 Cage migration 1 Medial pedicle Violation 2 Revision surgeries	Latter 32 Patients < OR Time, < EBL < Duration surgery Complications: 2 pseudarthrosis 1 early surgery infection (3 revision operations)
Park[31] 2015	Learning Curve 124 MI TLIF 9% (11) Perioperative Complications Learning Curve 8 -First 1/3 of series (41 Cases) 3 -Last 2/3 series	3 Temporary neuralgia 2 Deep Infections, 2 Screw misplacements 2 Cage migrations 1 Dural tear 1 Grafted extrusion	6% (7/124) Reoperations 2 Cage migration 2 Misplaced screws 1 Extruded graft 2 Infected cages)
Ahn[1] 2016	228 MI Lumbar Decompression (LD) Laminectomy or Laminotomy with/ without Diskectomy, Learning Curve, One Surgeon	50 Open 1-2 level MI Lumbar Decompressions (LD: > OR Time, > EBL, > LOS	50 MI LD 1-2 Level: < OR time, < EBL Same Readmission rate Both Groups Conclusion; no learning curve for MI LD

PLF: Posterolateral lumbar fusion, TLIF: Transforaminal lumbar interbody fusion, MIS/MI: Minimally invasive surgery, DT: Dural tears, EBL: Estimated blood loss, LOS: Length of stay, RCT: Randomized controlled trials, BMP: Bone morphogenetic protein, HO: Heterotopic ossification, PLIF: Posterior lumbar interbody fusion, TLIF: Transforaminal lumbar interbody fusion, LLIF: Extreme lateral lumbar fusions, XLIF: Extreme lateral lumbar fusions, OR: Operative room, LD: Lumbar decompressions

Wong *et al*. (2015), out of 513 MI TLIF, there was a 2.3% instrumentation failure rate.[40] Liu *et al*. (2016) found that 2 (1.9 %) of 101 TLIF (101 patients) required additional surgery for instrument failure.[23] Bakhsheshian *et al*. (2016) noted that for 513 MI TLIF, 8 (1.6%) required reoperations; 7 (1.4%) for cage extrusions, and 1 (0.2%) for an epidural hematoma.[3] Of interest, the average cost of a reoperation was an additional $17,271.

Up to 8.3% infection rates for minimally invasive transforaminal interbody lumbar fusion (MI TLIF)

Spinal infections occurred in from 0.2% up to 8.3% of patients undergoing predominantly MI TLIF [Tables 3–5].[19,23,31,40] Out of the 513 MI-TLIF, Wong *et al*. (2015) found a 1.4% incidence of medical, and a 0.2% frequency of surgical infections.[40] Joseph *et al*. (2015) observed a 1.6% risk of infection for MI-TLIF (5454 patients; 6040 levels fused; 4 studies) [Table 4].[19] In Park *et al*. (2015), there were 2 infected cages, and additional operations were required in 6% of patients [Table 4].[31] Liu *et al*. (2016) found 5 (5%) cases of infections out of a series of 101 TLIF [Table 5].[23] In comparison, there were no reopertions for infections in Epstein's two series: (1) no infections out of 137 patients undergoing 2-3 vs. 4-6 level laminectomies without fusions, and no infections out of 336 lumbar laminectomies with accompanying noninstrumented fusions.[15,16]

Mortality rates reported higher for transforminal interbody lumbar fusion (TLIF) vs. posterolateral lumbar fusion (PLF)

When Norton *et al*. (2015) reviewed 48,911 patients (237,383 procedures) from the Nationwide Inpatient

Sample Database (2001 to 2010) with degenerative lumbar disease/DS, those undergoing TLIF had higher morality rates vs. those having posterolateral lumbar fusions (PLF). Indeed, performance of PLF correlated with lower mortality rates, reduced hospital charges, LOS, and complication rates) [Table 4].

Restricted field of vision for minimally invasive transforaminal interbody lumbar fusion (MI TLIF)

Although Saetia *et al*. (2013) found similar complication rates of 8.3% for both open TLIF vs. MI TLIF for lumbar degenerative spondylolisthesis, the authors noted shortcomings of MI TLIF, including a restricted filed of vision (e.g. more limited exposure) that "required a very thorough knowledge of anatomy" [Table 3].[34] Although all surgeons need to have a thorough knowledge of the spinal anatomy whether performing open or MI procedures, surgeons performing MI surgery may lose perspective regarding the anatomy which can lead to higher complication rates.

Comparable outcomes for minimally invasive transforaminal lumbar fusion (MI TLIF) vs. other instrumented fusions including posterolateral lumbar fusion (PLF)

Multiple studies documented similar outcomes for MI TLIF/TLIF vs. other types of instrumented lumbar fusions (e.g., particularly PLF) [Tables 3–5].[17,18,41] Hoy *et al*. (2013) found comparable outcomes for TLIF (51 patients) vs. instrumented posterolateral fusions (PLF: 47 patients) [Table 3].[18] Giorgi *et al*. (2015) evaluated MI TLIF; although the fusion rate was just 72.6% at 1 postoperative year, the quality of outcomes were similar whether or not the patient successfully fused [Table 4].[17] In a meta-analysis involving 2 randomized controlled studies (RCTs) and 5 other studies (total 630 patients), Zhang *et al*. (2016) confirmed the comparable efficacy of 325 TLIF vs. PLF fusions for degenerative lumbar spondylosis [Table 5].[41] Specifically, TLIF did not increase the fusion rate compared with instrumented PLF, and there were no significant differences in outcomes (VAS, Oswestry Disability Index), reoperation rates, complications, duration of surgical procedures, blood loss, and duration of hospitalization.

BMP/INFUSE (Medtronic, Memphis, TN, USA) increased risks and complications for lumbar fusions including posterior lumbar interbody fusion (PLIF)/transforaminal interbody fusion/minimally invasive transforaminal interbody fusion (TLIF/MI TLIF)

BMP (bone morphogenetic protein)/INFUSE (Medtronic, Memphis, TN, USA) was and is still frequently applied "off-label" (e.g. posteriorly in the lumbar spine) for performing posterior lumbar spinal fusions including PLIF/TLIF/MI TLIF, thus increasing the risks and complication rates [Tables 3–5].[4,7,8-10,24,26,30,39] Wong *et al*. (2008) showed BMP/INFUSE used for PLIF and TLIF contributed to new neurological deficits due to significant ectopic bone formation (heterotopic ossification: HO) within the spinal canal [Table 3].[39] Mroz *et al*. (2010) noted the "off-label" use of BMP for TLIF was responsible for the following cage-related complications: a 44% resorption rate, a 25% subsidence rate, and 27% incidence of cage migration [Table 3].[26] Balseiro *et al*. (2010) additionally observed vertebral osteolysis (bone resorption) occurring following TLIF procedures, largely attributed to extremely high concentrations of BMP/INFUSE, and/or violation of end plates, resulting in subchondral cysts [Table 3].[4] Mannion *et al*. (2010) noted that, following TLIF performed with BMP/INFUSE, revision surgeries (4 PLIFs and 32 TLIFs) were much more "difficult" [Table 3].[24] Of the 30 complications noted in 240 TLIF using BMP/INFUSE in Owens *et al*. series (2010), 5 complications were directly attributed to BMP/INFUSE – 1 nonunion at 12 months (osteolysis), 2 with heterotopic ossification, and 2 exhibiting perineural cysts associated with migration of interbody cages.[30] In 2011, Epstein observed BMP/INFUSE was used off-label in the spine 96% of the time at one institution, and cited multiple other reports of BMP/INFUSE-related morbidity particularly associated with TLIF surgery [Table 3].[8,9] In 2013, both Epstein and Chrastil separately summarized multiple adverse events attributed to the off-label use of BMP/INFUSE in spine surgery; these included heterotopic ossification (HO), osteolysis, infection, adhesive arachnoiditis, increased postoperative neurological deficits/radiculitis, endplate osteolysis/interbody device subsidence, retrograde ejaculation/sterility, and cancer.[7,10]

Obviously, the use of BMP/INFUSE for TLIF/MI TLIF, PLIF and other instrumented fusions introduces additional complications not seen with the laminectomy alone/laminectomy with non instrumented fusion where BMP is not utilized.

Learning curve for minimally invasive surgery/transforaminal interbody lumbar fusion (MI TLIF)

In 2011, Payer utilized the PubMed and Medline databases and found only 9 RCT that adequately defined the pros and cons of MI lumbar decompressions/stabilization procedures.[33] Although the pros included smaller incisions, reduced perioperative pain, blood loss, and hospital stays, the cons included steep learning curves, they observed there was no relevant benefit from minimally invasive techniques (e.g., decompression/stabilization-fusion), and a tendency for more safety in open procedures for lumbar disc herniations, TLIF, and PLIF.

Learning curves: 33–44 cases for minimally invasive transforaminal interbody lumbar fusion (MI TLIF) vs. 0 for minimally invasive decompressions alone

The learning curve for MI TLIF, defined as how many MI TLIF a surgeon needs to perform before becoming technically proficient, was described as involving the first 33–44 cases (e.g. reported in 4 series) [Table 6].[1,22,27,31,37] In a study by Silva *et al*. (2013), for 110 patients undergoing 1-level and 18 patients undergoing 2-level MITLIF, a 90% learning milestone was achieved by the 39th case, with an overall complication rate of 12.67%.[37] Nandyala (2014) observed that 90% of the learning curve for 65 consecutive patients undergoing MI TLIF, addressing disk disease or lumbar spinal stenosis with grade I or II spondylolisthesis (2008–2011), was attained at about the 40th case.[27] Of interest, for the first 33 patients in Nandyala study (2014), the average operative time/duration of anesthesia for MIS TLIF was longer, there was more blood loss, and there were more complications (e.g., 2 radiographic pseudarthroses, 1 graft migration, 1 medial pedicle wall violation necessitating two operative revisions).[27] Alternatively, for the latter 32 patients, there were 2 pseudarthroses and 1 early surgical site infection; all 3 patients required revision surgery. For Lee *et al*. (2014), the learning curve for MI TLIF was 44 cases (e.g., total 90 cases 2005–2009 performed by a single surgeon); for the 44 initial cases, there were 3 complications – 1 incidental durotomy and 2 asymptomatic cage migrations, while for the latter 46 patients, there was just 1 asymptomatic cage migration.[22] Other observations for the latter 46 patients included reduced operative times, radiation dose, postoperative pain, and fewer new postoperative neurogenic symptoms. In 2015, Park *et al*. defined the learning curve for 124 MI TLIF as occurring after the first one-third of the cases (41 MI TLIF).[31] Notably, 8 of the total 11 complications occurred in the first 41 cases, with only 3 occurring in the remaining two-thirds of the patients (e.g., latter 83 patients). Total complications included 3 temporary postoperative neuralgias, 2 deep wound infections, 2 pedicle screw misplacements, 2 cage migrations, 1 dural tear, and 1 bone graft extrusion [Table 6].[31] In contrast, Ahn *et al*. documented no learning curve (e.g., no or 0 cases) required for learning how to safely and proficiently perform MI lumbar decompressions alone (LD).[1] They based this conclusion on an analysis of 50 open 1–2 level lumbar decompressions (LD) performed from 2005 to 2006 vs. 50 subsequent MI LD. They concluded "although surgical experience may improve perioperative parameters (operative time, length of hospitalization), a MIS LD may initially be performed safely without prior experience." The results of Ahn *et al*. clearly indicate that there was no learning curve needed to perform MI lumbar decompressions. This does not, however, necessarily fit in with the experience of many surgeons learning any new operation including the simplest in which there is always some learning curve.

Increased relative frequency, costs, and reimbursement for instrumented lumbar fusions vs. lumbar laminectomy alone

Several studies documented the increased frequency, costs, and reimbursement rates for instrumented fusion vs. lumbar laminectomy alone addressing degenerative lumbar disease with/without DS.[5,25,42] Utilizing the Nationwide Inpatient Sample (NIS) plus US Census/other data, Bernstein *et al*. (2017) determined that from 2003 to 2012 the number of lumbar diskectomies decreased by 19.8% and laminectomies by 26.1%, while there was an increase of 56.4% in the incidence of lumbar spinal fusions.[5] Menger *et al*. (2015), evaluating Medicare data from 2012, found that for 206 spinal surgeons performing lumbar laminectomies (including add-on levels)/fusions), the average neurosurgeon was paid \$142,075 for all procedures.[25] In 2017, Zygourakis *et al*. (2017), utilizing the 2001 to 2013 National Inpatient Sample database, evaluated the different costs for performing discectomy/laminectomy (181,267 patients) vs. instrumented lumbar fusions (433,364 patients) in different locations in the US.[42] The average cost increases from 2001 to 2013 were \$8,316 to \$11,405 for discectomy/laminectomy vs. \$21,473 to \$29,438 for instrumented fusions (e.g., a 2.6 fold increased cost for fusions). Notably, higher costs for fusions were also encountered at smaller hospitals in more rural locations. Thus, if a surgeon added a fusion to his or her procedure, the reimbursement would increase over 2.6 times.

DISCUSSION

In this review of the literature, for patients with lumbar degenerative disease/with or without DS, we found lower complication and reoperation rates utilizing laminectomy alone vs. instrumented fusions (e.g., predominantly MI TLIF). For 2 years following Epstein's 137 lumbar multilevel laminectomies without fusions, patients exhibited no new neurological deficits, no infections, 4 (2.9%) had intraoperative CSF fistulas, there were no readmissions, and just 1 patient (0.73%) required a reoperation.[16] Other literture showed a 4.8% complication rate for laminectomy alone vs. 8.3% for instrumented fusions; at 5 postoperative years, the reoperation rates were lower (10.6%) without than with instrumented procedures (18.4%). Furthermore, complication rates for predominantly MI TLIF ranged up to (23.04%); reoperations up to 6%, accompanied by a learning curve requiring 33–44 of the initial cases to attain proficiency compared to 0% necessitated for safely performing MI laminotomy.

Based on these data, the choice of procedures to address multilevel degenerative lumbar disease with/without DS should be obvious. Nevertheless, more fusions rather than decompressions alone are increasingly being performed. For example, Bae *et al*. (Nationwide Inpatient Sample Data) showed that, from 2004 to 2009, decompressions alone decreased from 58.5% to 49.2%, but "simple fusions" (1–2 disc levels/single approach) increased from 21.5% to 31.2%.[2] Using the National Inpatient Sample database, Zygourakis *et al*. (2017) showed the average cost for discectomy/laminectomy increased in 2001–2013 from $8,316 to $11,405, while for fusions it increased 2.6 fold ($21,473 to $29,438).[42] Furthermore, when Menger *et al*. (2015) utilized Medicare data from 2012 for 206 spinal surgeons, they documented neurosurgeon reimbursements for all lumbar fusions averaged $142,075 (e.g., lumbar laminectomies/add-on levels/fusions).[25] As both hospital charges and physician reimbursements are higher for more complicated fusions, one cannot dismiss financial gain as an added motivation for performing lumbar fusions. Certainly, our selection of operative alternatives for treating degenerative lumbar disease/DS must uphold the standard of care that "must be justified on a logical basis and must have considered the risks and benefits of competing options."[35]

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Conflicts of interest

There are no conflicts of interest.

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