

Perioperative outcomes in minimally invasive lumbar spine surgery: A systematic review

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Abstract

AIM: To compare minimally invasive (MIS) and open techniques for MIS lumbar laminectomy, direct lateral and transforaminal lumbar interbody fusion (TLIF) surgeries with respect to length of surgery, estimated blood loss (EBL), neurologic complications, perioperative transfusion, postoperative pain, postoperative narcotic use, and length of stay (LOS).

METHODS: A systematic review of previously published studies accessible through PubMed was performed. Only articles in English journals or published with English language translations were included. Level of evidence of the selected articles was assessed. Statistical data was calculated with analysis of variance with $P < 0.05$ considered statistically significant.

RESULTS: A total of 11 pertinent laminectomy studies, 20 direct lateral studies, and 27 TLIF studies were found. For laminectomy, MIS techniques resulted in a significantly longer length of surgery (177.5 min *vs* 129.0 min, $P = 0.04$), shorter LOS (4.3 d *vs* 5.3 d, $P = 0.01$) and less perioperative pain (visual analog scale: 16 ± 17 *vs* 34 ± 31 , $P = 0.04$). There is evidence of decreased narcotic use for MIS patients (postoperative intravenous morphine use: 9.3 mg *vs* 42.8 mg), however this difference is of unknown significance. Direct lateral approaches have insufficient comparative data to establish relative perioperative outcomes. MIS TLIF had superior EBL (352 mL *vs* 580 mL, $P < 0.0001$) and LOS (7.7 d *vs* 10.4 d, $P < 0.0001$) and limited data to suggest lower perioperative pain.

CONCLUSION: Based on perioperative outcomes data, MIS approach is superior to open approach for TLIF. For laminectomy, MIS and open approaches can be chosen based on surgeon preference. For lateral approaches, there is insufficient evidence to find non-inferior perioperative outcomes at this time.

Key words: Minimally invasive; Spine surgery; Lumbar

spine; Perioperative outcomes; Estimated blood loss; Neurologic complications; Transfusion; Postoperative pain; Narcotic use; Length of stay; Length of surgery

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Core tip: Perioperative outcomes in minimally invasive (MIS) approaches to the lumbar spine have not been specifically examined in systematic reviews of MIS lumbar laminectomy, direct lateral and transforaminal lumbar interbody fusion (TLIF) surgeries. Based on perioperative outcomes data, MIS approach is superior to open approach for TLIF. For laminectomy, MIS and open approaches can be chosen based on surgeon preference. For lateral approaches, there is insufficient evidence to find non-inferior perioperative outcomes at this time.

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INTRODUCTION

Minimally invasive surgical (MIS) approaches to lumbar spinal surgery have been an area of increasing clinical interest for over 50 years. Percutaneous approaches to lumbar disk herniation began with chemonucleolysis treatment for sciatica by Smith^[1] in 1964. In 1997, Smith^[1] and Foley *et al*^[2] introduced the tubular distraction system for a microendoscopic approach to microdiscectomy. This system allowed direct visualization of the surgical field while minimizing dissection and distraction of the paraspinal muscles and thoracolumbar fascia. By reducing the size of the operative field and reducing the number of damaged blood vessels, muscles and fascial structures, blood loss and post-operative pain would be reduced, leading to a shorter hospital stay, faster time to mobilization, and reduced post-operative analgesia needs.

After the development of the microendoscopic microdiscectomy, there were a series of rapid advances, applying the technology to other surgeries. In 1998, McAfee *et al*^[3] described the direct lateral interbody fusion (DLIF) as an alternative to anterior lumbar interbody fusion (ALIF). Foley *et al*^[4] described the MIS transforaminal lumbar interbody fusion (TLIF) in 2003, followed by Mummaneni *et al*^[5] detailing the Mini-Open TLIF. In 2006, Ozgur *et al*^[6] described the extreme lateral interbody fusion (XLIF) as another minimally invasive alternative to the ALIF. In 2010, a new, purely percutaneous approach for laminotomy and decompression, the Minimally Invasive Lumbar Decompression (mild[®]), was described by Chopko *et*

al^[7].

The initial hope that MIS approaches to the lumbar spine would lead to long-term reductions in patient-reported pain relative to open approaches has not yet been substantiated. Most studies of long-term results have reported similar outcomes between MIS and traditional open surgeries^[8-10]. This leaves short-term measures, specifically perioperative outcomes, as the main possible distinguishing clinical feature between MIS lumbar spinal surgery and open surgical technique. There have not been any systematic reviews specifically focusing on perioperative outcomes across minimally invasive lumbar spinal surgical modalities, nor have there been systematic reviews of either minimally invasive laminectomy or far lateral fusion approaches.

This systematic review examines perioperative outcomes in minimally invasive lumbar spinal surgeries across several surgery types for adult degenerative spine disease: (1) MIS laminectomy vs open laminectomy; (2) MIS TLIF vs open TLIF; and (3) MIS XLIF and DLIF vs ALIF.

MATERIALS AND METHODS

A series of searches using the PubMed-National Library of Medicine/National Institutes of Health (www.ncbi.nlm.nih.gov) database were performed. Only articles in English journals or published with English abstracts were included. Level of evidence of the selected articles was assessed. Search keywords included: "minimally invasive", "spine surgery", "laminectomy", "TLIF", "DLIF", "XLIF", and "ALIF". Abstracts were reviewed for clinical studies that reported perioperative outcomes in relevant surgical intervention categories (Figure 1).

Laminectomy

Studies were only included if they categorically used "laminectomy" for all subjects. Kinoshita *et al*^[11] performed laminotomies for single level decompression, and sometimes performed laminectomies for multiple level decompression. It can be argued that laminotomy vs laminectomy is a distinction without a difference, but including laminotomies would then bring a number of microdiscectomy techniques into the range of covered studies. As this would introduce significant heterogeneity into the category, only studies describing laminectomy as part of the decompression surgery were included in the laminectomy category.

TLIF

TLIF studies were included regardless of whether bilateral or unilateral instrumentation was used. Only studies with both an open TLIF and an MIS TLIF arm were included. Studies that compared MIS TLIF with posterior lumbar interbody fusion (PLIF) or did not report TLIF and PLIF results separately were excluded.

DLIF/XLIF

Axial lumbar interbody fusion (AxialLIF) studies were

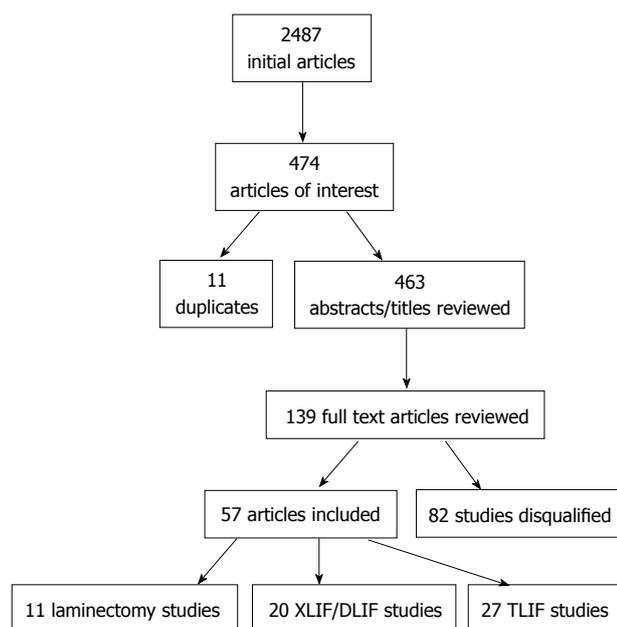


Figure 1 Identified pertinent studies from the literature search. TLIF: Transforaminal lumbar interbody fusion; DLIF: Direct lateral interbody fusion; XLIF: Extreme lateral interbody fusion.

not included. Studies with large portions of the study population receiving dual fixation (XLIF plus PLIF) were excluded.

Perioperative outcomes of interest examined in this systematic review include the following: (1) Length of surgery; (2) Estimated blood loss (EBL); (3) Neurologic complications; (4) Perioperative transfusion; (5) Postoperative pain; (6) Postoperative narcotic use; and (7) Length of stay (LOS).

Results were tabulated by intervention, indication for intervention, data by study arm, and relevant qualifications (bias, observer status, *etc.*) gathered. Multiple reports of the data from the same patient population were disregarded. Data from similar studies was pooled and calculated with analysis of variance (ANOVA). Numerical data that was reported stratified into subgroups other than MIS/non-MIS, were re-pooled and calculated with ANOVA. Numerical data only reported in graph form were incorporated using graphical methods. Durotomy and cerebrospinal fluid leak were included as reportable neurologic complications. Incorporation of isolated additional neurologic complications resulted in some study groups having complication rates above 100%. In order to summarize data across studies, joint statistics were calculated using ANOVA. The statistical review of this study was performed by a biomedical statistician.

RESULTS

Overall results

No studies found used independent observers for EBL or neurologic complications. At least two studies reported change in hemoglobin, presumably independently

measured, but did not separately report patient fluid balance^[12,13]. No studies used defined criteria for or an independent or blinded observer to decide the following study parameters: (1) Hospital discharge eligibility (*i.e.*, LOS); (2) Opiate prescription or availability; and (3) Need for perioperative transfusion.

Laminectomy

Identified pertinent studies are shown in Table 1, including three randomized controlled trials (RCTs) (Cho *et al.*^[14], Usman *et al.*^[15] and Watanabe *et al.*^[16]), one incompletely randomized trial (Mobbs *et al.*^[17]; randomized by consecutive, odd/even patient order^[18]), and one cohort comparison study^[12]. In Table 2, results for length of surgery, EBL, rate of neurologic complications, and LOS are shown. Pooling across RCTs/incomplete-RCTs with published standard deviations, length of surgery was significantly longer for MIS surgeries than open surgeries (177.5 min vs 129.0 min, $P = 0.004$), EBL was non-significantly less in MIS surgeries (115.0 mL vs 102.1 mL, $P = 0.580$), and LOS was significantly shorter following MIS surgeries than open surgeries (4.3 d vs 5.3 d, $P = 0.010$). Pooled rates of neurological complications in the two RCTs specifically reporting complications by group showed non-significantly higher rates of complications in open procedures (2.0% MIS vs 4.3% open, $P = 0.52$).

Three studies specifically examined rates of post-operative pain in these patient groups. Watanabe *et al.*^[16] examined the visual analog scale (VAS) score for post-operative wound pain on post-operative day 7 and found a VAS of 16 (± 17) for MIS patients and a VAS of 34 (± 31) for open laminectomies, a statistically significant difference ($P = 0.04$). Mobbs *et al.*^[17] examined post-operative narcotic use during hospital stay and found an intravenous morphine equivalent of 9.3 mg in MIS patients and 42.8 mg in open patients, a difference of unknown statistical significance (P value not stated). Komp *et al.*^[21] reported that “no operation-related pain medication was required” in their MIS case series.

No studies reported a need for transfusions following either MIS or open laminectomy.

DLIF/XLIF

No randomized trials using an ALIF control arm were identified in the literature search. One RCT had XLIF as part of the intervention in both the study arm and control arm groups^[25]. Two studies mixed traumatic and/or post-infectious patients in the study population; as these indications were in the minority in each of these studies, the studies were included^[13,26].

Identified pertinent studies are shown in Table 3, including four cohort control studies and 15 case series. In Table 4, results for length of surgery, EBL, rate of neurologic complications, and LOS are shown. In the authors’ opinion, the current non-randomized data does not justify pooling or a meta-analysis due to heterogeneity and potential bias. Only one study (Huang

Table 1 Studies evaluating minimally invasive laminectomy

Ref.	Year	Surgery	Population	MIS patients	Open patients
RCTs/IRCTs					
Cho <i>et al</i> ^[14]	2007	Split process laminectomy: Marmot operation	LSS	40	30
Usman <i>et al</i> ^[15]	2013	Unilateral laminectomy	LSS, no spondylolisthesis	30	30
Mobbs <i>et al</i> ^[17]	2014	Laminectomy: Unilateral laminectomy for bilateral decompression	LSS, max 2 levels, no spondylolisthesis	27	27
Watanabe <i>et al</i> ^[16]	2011	Lumbar spinous process-splitting laminectomy	Neurogenic claudication	22	19
Clinical case series					
Rahman <i>et al</i> ^[18]	2008	Laminectomy	LSS, no discectomy	38	88
Nomura <i>et al</i> ^[19]	2014	Laminectomy: Spinous process-splitting laminectomy	Spondylolisthesis, LSS due to herniation	124	-
Parikh <i>et al</i> ^[20]	2008	Laminectomy	Degenerative disease	75	-
Komp <i>et al</i> ^[21]	2011	Laminectomy: Unilateral laminectomy for bilateral decompression	LSS, no spondylolisthesis > 1	74	-
Nomura <i>et al</i> ^[22]	2012	Laminectomy: Unilateral laminectomy for bilateral decompression: Paramedian approach	LSS, no discectomy	70	-
Tomasino <i>et al</i> ^[23]	2009	Laminectomy: Unilateral laminectomy for bilateral decompression	LSS, herniation in obese	28	-
Wada <i>et al</i> ^[24]	2010	Laminectomy	LSS, elderly patients	15	-

RCT: Randomized controlled trial; IRCT: Incomplete randomized controlled trial; LSS: Lumbar spinal stenosis; MIS: Minimally invasive.

Table 2 Studies comparing perioperative outcomes of minimally invasive laminectomy vs open laminectomy

	Length of surgery (min) ± SD		Estimated blood loss (cc) ± SD		Neurologic complications		Length of stay (d) ± SD	
	MIS	Open	MIS	Open	MIS	Open	MIS	Open
RCTs/IRCTs								
Cho <i>et al</i> ^[14]	259 ± 122	193 ± 68	154 ± 135	132 ± 128	-	-	4.0 ± 2.9	7.2 ± 1.6
Usman <i>et al</i> ^[15]	69 ± 0.1	65 ± 0.1	-	-	-	-	4.7 ± 0.5	3.5 ± 0.5
Mobbs <i>et al</i> ^[17]	-	-	40	110	4%	7%	2.3	4.2
Watanabe <i>et al</i> ^[16]	69 ± 29	82 ± 36	44 ± 75	55 ± 48	0%	0%	-	-
Clinical case series								
Rahman <i>et al</i> ^[18]	110 ± 10	157 ± 7	52 ± 14	246 ± 32	5%	8%	2.1 ± 0.7	4.1 ± 0.4
Nomura <i>et al</i> ^[19]	187 ± 68	-	90 ± 94	-	2%	-	-	-
Parikh <i>et al</i> ^[20]	118 ± 40	-	41 ± 90	-	11%	-	1.2	1.3
Komp <i>et al</i> ^[21]	44	-	0 ¹	-	14%	-	-	-
Nomura <i>et al</i> ^[22]	77 ²	-	15.0 ²	-	0%	-	-	-
Tomasino <i>et al</i> ^[23]	102 ± 44	-	35 ± 76	-	11%	-	2.1	2.2
Wada <i>et al</i> ^[24]	144	-	60	-	7%	-	-	-

¹No measurable blood loss; ²Per level. SD: Standard deviation; RCT: Randomized controlled trial; IRCT: Incomplete randomized controlled trial; MIS: Minimally invasive.

et al^[29]) was a prospectively designed and enrolled study; and, it used an approach (minimal access ALIF) that has not been repeated in any other study.

Within the reported data for MIS anterior fusion approaches, average length of surgery varied from 27 min to 295 min, average EBL from “not measureable” to 572 mL, and neurologic complication rates varied from 0% to 130%.

Two studies reported on perioperative transfusion use in this patient population. Hrabalek *et al*^[27] reported a 0% transfusion use in the MIS XLIF and open ALIF cohorts. Rodgers’s 2010 study, focusing on patients 80 years of age and older, reported no use of perioperative transfusion in MIS XLIF patients, but a 70% rate of transfusion in PLIF patients^[12]. Regarding non-controlled studies, Rodgers *et al*^[13] reported a 0.2% rate of transfusion in XLIF patients, while Berjano *et al*^[34] reported a 1% transfusion rate.

Three non-controlled studies reported on peri-

operative pain and narcotic use in patients treated with lateral interbody fusion. Ruetten *et al*^[30] reported a mean VAS back of 4 (out of 100) and a VAS leg of 14 (out of 100) on post-operative day 1, stating that no post-operative pain medication was required in their 463 patient series. Marchi *et al*^[35] reported mean VAS back of 45 and VAS leg of 31 one week following surgery, while Pimenta *et al*^[40] reported a combined VAS Back/Leg value of 50 at the same time point.

Virtually all of the data gathered involved application of the XLIF (NuVasive, San Diego, California, United States) system; there is at this point limited data on other systems.

TLIF

Identified pertinent studies are shown in Table 5, including 1 RCT (Wang *et al*^[43]) and 2 incompletely randomized controlled trials (Shunwu *et al*^[44]: Randomized by admission date; Wang *et al*^[45]: randomized by conse-

Table 3 Studies on minimally invasive lateral approaches to the lumbar spine

Ref.	Year	Surgery	Type of study	Population	MIS patients	Open patients
Cohort studies						
Hrabalek <i>et al</i> ^[27]	2014	XLIF	Retrospective cohort, XLIF <i>vs</i> ALIF	DDD, FBSS, spondylolisthesis	88	120
Smith <i>et al</i> ^[28]	2012	XLIF	Retrospective cohort, XLIF <i>vs</i> ALIF	DDD, LSS, FBSS, spondylolisthesis, herniation	115	87
¹ Rodgers <i>et al</i> ^[12]	2010	XLIF	Retrospective cohort, XLIF <i>vs</i> PLIF	> 80 yr, LSS, FBSS spondylolisthesis, scoliosis, fracture	40	20
Huang <i>et al</i> ^[29]	2010	MIS-ALIF ²	Prospective cohort, MIS-ALIF <i>vs</i> ALIF	Not defined	10	13
Case series						
³ Rodgers <i>et al</i> ^[13]	2011	XLIF	PCS	LSS, DDD, FBSS, spondylolisthesis, scoliosis	600	-
Ruetten <i>et al</i> ^[30]	2005	XLIF	RCS	Lumbar disc prolapse	463	-
Lykissas <i>et al</i> ^[31]	2014	XLIF	RCS	Degenerative spinal conditions	144	-
Grimm <i>et al</i> ^[32]	2014	XLIF	RCS	DDD, LSS, FBSS, scoliosis, spondylolisthesis, herniation	108	-
Tohmeh <i>et al</i> ^[33]	2011	XLIF	PCS	LSS, DDD, spondylolisthesis, spondylosis, scoliosis, recurrent herniation, ASD	102	-
Berjano <i>et al</i> ^[34]	2012	XLIF	RCS	DDD, LSS, spondylolisthesis	97	-
Lee <i>et al</i> ^[26]	2014	DLIF	RCS	LSS, spondylolisthesis, scoliosis, post-infectious	90	-
Marchi <i>et al</i> ^[35]	2012	XLIF	PCS	Spondylolisthesis	52	-
Sharma <i>et al</i> ^[36]	2011	XLIF	RCS	Spondylosis ± listhesis, scoliosis	43	-
Pimenta <i>et al</i> ^[25]	2011	XLIF	PCS	DDD	36	-
Ahmadian <i>et al</i> ^[37]	2013	XLIF	RCS	L4/L5 spondylolisthesis	31	-
Caputo <i>et al</i> ^[38]	2012	XLIF	PCS	Scoliosis	30	-
Malham <i>et al</i> ^[39]	2012	XLIF	PCS	DDD, spondylolisthesis, scoliosis	30	-
⁴ Pimenta <i>et al</i> ^[40]	2013	XLIF	RCT	L4/L5 DDD	30	-
Elowitz <i>et al</i> ^[41]	2011	XLIF	PCS	LSS	25	-
Oliveira <i>et al</i> ^[42]	2010	XLIF	PCS	Degenerative spinal conditions	21	-

¹Author financial conflict, different time period for cohort; ²Minimally invasive flank incision; ³Reported data likely includes data separately reported in Rodgers *et al*^[13]; ⁴This randomized control trial did not have an open surgery arm. DDD: Degenerative disc disease; FBSS: Failed back surgery syndrome; LSS: Lumbar spinal stenosis; ASD: Adjacent segment disease; MIS: Minimally invasive; RCT: Randomized controlled trial; XLIF: Extreme lateral interbody fusion; ALIF: Axial lumbar interbody fusion; PCS: Prospective cohort study; RCS: Retrospective cohort study; PLIF: Posterior lumbar interbody fusion; DLIF: Direct lateral interbody fusion.

Table 4 Studies comparing perioperative outcomes of minimally invasive lateral *vs* open anterior approaches to the lumbar spine

Ref.	Length of surgery (min) ± SD		Estimated blood loss (cc) ± SD		Neurologic complications		Length of stay (d) ± SD	
	MIS	Open	MIS	Open	MIS	Open	MIS	Open
Cohort studies								
Hrabalek <i>et al</i> ^[27]	-	-	-	-	28%	24%	-	-
Smith <i>et al</i> ^[28]	112 ± 31	173 ± 31	90 ± 74	311 ± 370	3%	6%	1.7 ± 1.3	3.6 ± 0.9
Rodgers <i>et al</i> ^[12]	-	-	1.4 g Hb	2.7 g Hb	-	-	1.3	5.3
Huang <i>et al</i> ^[29]	176 ± 8	202 ± 15	572 ± 93	970 ± 209	-	-	11.6 ± 1.3	12.5 ± 1.3
Case series								
Rodgers <i>et al</i> ^[13]	-	-	1.38 g Hb	-	1%	-	1.2	-
Ruetten <i>et al</i> ^[30]	27	-	0 ¹	-	0%	-	-	-
Lykissas <i>et al</i> ^[31]	295 ± 180	-	-	-	135%	-	-	-
Grimm <i>et al</i> ^[32]	122	-	181	-	20%	-	3.0	-
Tohmeh <i>et al</i> ^[33]	-	-	-	-	48%	-	-	-
Berjano <i>et al</i> ^[34]	-	-	-	-	16%	-	-	-
Lee <i>et al</i> ^[26]	52 ± 19	-	0 ¹	-	19%	-	-	-
Marchi <i>et al</i> ^[35]	73 ± 31	-	< 50	-	29%	-	-	-
Sharma <i>et al</i> ^[36]	-	-	-	-	70%	-	-	-
Pimenta <i>et al</i> ^[25]	130	-	-	-	28%	-	1.4	-
Ahmadian <i>et al</i> ^[37]	-	-	94	-	-	-	3.5	-
Caputo <i>et al</i> ^[38]	-	-	-	-	2	-	-	-
Malham <i>et al</i> ^[39]	84	-	70	-	20%	-	-	-
Pimenta <i>et al</i> ^[40]	69 ± 11	-	< 50	-	13%	-	-	-
Elowitz <i>et al</i> ^[41]	-	-	-	-	20% ³	-	-	-
Oliveira <i>et al</i> ^[42]	86	-	44	-	14%	-	1.2	-

¹“Non-measurable” blood loss; ²Anterior thigh numbness in “substantial percentage” of patients which resolved in all patients at 4 wk; ³Anterior thigh numbness for more than 3 wk. Hb: Hemoglobin; SD: Standard deviation; MIS: Minimally invasive.

Table 5 Studies on minimally invasive transforaminal lumbar interbody fusion

Ref.	Year	Surgery	Population	MIS patients	Open patients
RCTs/IRCTs					
Wang <i>et al</i> ^[443]	2011	TLIF	LSS, herniation, spondylolisthesis	41	38
Shunwu <i>et al</i> ^[444]	2010	TLIF	Degenerative lumbar disease	32	30
Wang <i>et al</i> ^[445]	2011	TLIF	Failed discectomy and decompression	25	27
Cohort studies					
Wong <i>et al</i> ^[446]	2014	TLIF	FBSS, DDD, spondylolisthesis	144	54
Zhang <i>et al</i> ^[447]	2013	TLIF	DDD	82	76
Villavicencio <i>et al</i> ^[448]	2010	TLIF	LSS, DDD ± herniation, spondylolisthesis	76	63
Lee <i>et al</i> ^[449]	2012	TLIF	LSS, DDD, herniation, spondylolisthesis	72	72
Terman <i>et al</i> ^[500]	2014	TLIF	DDD, LSS, spondylolisthesis, herniation	53	21
Cheng <i>et al</i> ^[511]	2013	TLIF	Spondylosis/listhesis, foraminal stenosis	50	25
Liang <i>et al</i> ^[522]	2011	TLIF	Degenerative lumbar instability	45	42
Yang <i>et al</i> ^[533]	2013	TLIF	Lumbar degenerative diseases	43	104
Gu <i>et al</i> ^[541]	2014	TLIF	Degenerative conditions	43	38
Wang <i>et al</i> ^[551]	2010	TLIF	Spondylolisthesis	42	43
Zairi <i>et al</i> ^[561]	2013	Mini open TLIF	DDD, spondylolisthesis	40	60
Seng <i>et al</i> ^[571]	2013	TLIF	DDD, spondylolisthesis	40	40
Pelton <i>et al</i> ^[581]	2012	TLIF	DDD, spondylolisthesis	33	33
Singh <i>et al</i> ^[591]	2014	TLIF	DDD, spondylolisthesis	33	33
Brodano <i>et al</i> ^[601]	2013	Mini open TLIF	DDD, spondylolisthesis	30	34
Zou <i>et al</i> ^[611]	2013	TLIF	LSS, spondylolisthesis, herniation	30	30
¹ Peng <i>et al</i> ^[621]	2009	TLIF	DDD, spondylolisthesis	29	29
Archavlis <i>et al</i> ^[631]	2013	TLIF	SDS and severe FJO	24	25
Dhall <i>et al</i> ^[641]	2008	Mini open TLIF	DDD, spondylolisthesis	21	21
Schizas <i>et al</i> ^[651]	2009	TLIF	DDD, spondylolisthesis	18	18
Adogwa <i>et al</i> ^[661]	2011	TLIF	Grade I spondylolisthesis	15	15
Niesche <i>et al</i> ^[671]	2014	TLIF	Recurrent lumbar disc herniation	14	19
Lau <i>et al</i> ^[681]	2011	TLIF	Spondylosis/listhesis/lysis	10	12

¹Differences in indications for study and control groups. LSS: Lumbar spinal stenosis; FBSS: Failed back surgery syndrome; DDD: Degenerative disc disease; SDS: Severe degenerative stenosis; FJO: Facet joint arthropathy; MIS: Minimally invasive; TLIF: Transforaminal lumbar interbody fusion; RCT: Randomized controlled trial; IRCT: Incomplete randomized controlled trial.

cutive, odd/even patient order). In Table 6, results for length of surgery, EBL, rate of neurologic complications, and LOS are shown. Pooling across RCTs and incompletely-RCTs with published standard deviations, length of surgery was non-significantly longer for MIS surgeries than open surgeries (150 min vs 143 min, $P = 0.09$), EBL was significantly less in MIS surgeries (352 mL vs 580.9 mL, $P < 0.0001$), and LOS was significantly shorter following MIS surgeries than open surgeries (7.7 d vs 10.4 d, $P < 0.0001$). Pooled rates of neurological complications in the two RCTs specifically reporting complications by group showed non-significantly higher rates of complications in open procedures (4.1% MIS vs 5.3% open, $P = 0.697$).

Regarding post-operative pain, Wang *et al*^[445] polled patients on post-operative day 2, finding a VAS back of 2.2 ± 0.6 in MIS patients and 4.3 ± 0.5 , a statistically significant difference ($P < 0.05$). Investigating the need for perioperative blood transfusions, Shunwu *et al*^[444] found that 0 of 32 of the MIS patients needed transfusion, while the 30 open patients needed an average of 0.40 units of blood (SD: 0.97), a significant difference ($P = 0.017$).

DISCUSSION

The current growing trends in the use of MIS approaches in lumbar spine surgery have led to a concerted effort to

compare outcomes between MIS and open techniques. Previous studies on long-term outcomes between MIS and open approaches in lumbar spine surgery have not revealed a significant difference between the two approaches^[8-10]. This is the first systematic review of perioperative outcomes in lumbar MIS lumbar spine surgery aiming to reveal differences between MIS and open techniques in terms of lengths of surgery, EBL, neurologic complications, perioperative transfusion, postoperative pain, postoperative narcotic use and LOS.

To facilitate the interpretation of the currently existing data, lumbar spine procedures were divided into different types including decompressive laminectomy and interbody fusions. Interbody fusions were further subdivided into TLIF and lateral vs anterior interbody fusions.

In decompressive laminectomy, this study found the muscle-sparing MIS approach to result in significantly longer operative times compared to the open approach (177.5 min vs 129.0 min, $P = 0.004$). Although decompressive lumbar laminectomy is a relatively straightforward spinal operation, there exists a steep learning curve associated with microscope-assisted tubular spinal surgery^[68], which could be one important factor accounting for the differences in operative times between the two techniques. With the growing popularity of minimally invasive approaches and the growing number of younger surgeons performing minimally

Table 6 Studies comparing perioperative outcomes of minimally invasive vs open transforaminal lumbar interbody fusion

Ref.	Length of surgery (min) ± SD		Estimated blood loss (cc) ± SD		Neurologic complications		Length of stay (d) ± SD	
	MIS	Open	MIS	Open	MIS	Open	MIS	Open
RCTs/IRCTs								
Wang <i>et al</i> ^[43]	168.7 ± 36.4	145.0 ± 26.8	207.7 ± 57.6	258.9 ± 122.2	2%	0%	6.4 ± 2.5	8.7 ± 2.1
Shunwu <i>et al</i> ^[44]	159.2 ± 21.7	142.8 ± 22.5	399.8 ± 125.8	517.0 ± 147.8	0%	0%	9.3 ± 2.6	12.5 ± 1.8
Wang <i>et al</i> ^[45]	139.0 ± 27.0	143.0 ± 35.0	291.0 ± 86.0	652.0 ± 150.0	12%	19%	-	-
Cohort studies								
Wong <i>et al</i> ^[46]	173	309	115	485	12%	13%	2.8	4.4
Zhang <i>et al</i> ^[47]	120 ± 35	115 ± 28	250 ± 75	650 ± 150	0%	3%	-	-
Villavicencio <i>et al</i> ^[48]	223 ± 68	215 ± 60	163 ± 131	367 ± 298	11%	13%	3.0 ± 2.3	4.2 ± 3.5
Lee <i>et al</i> ^[49]	166 ± 52	182 ± 45	161 ± 51	447 ± 519	1%	0%	3.2 ± 2.9	6.8 ± 3.4
Terman <i>et al</i> ^[50]	-	-	100	450	-	-	2.0	3.0
Cheng <i>et al</i> ^[51]	245 ± 73	279 ± 15	393 ± 284	536 ± 324	0%	12%	4.8 ± 1.8	6.1 ± 1.8
Liang <i>et al</i> ^[52]	127 ± 60	96 ± 46	194 ± 86	357 ± 116	-	-	-	-
Yang <i>et al</i> ^[53]	175 ± 35	177 ± 30	362 ± 177	720 ± 171	7%	2%	4.0 ± 1.3	7.1 ± 1.0
Gu <i>et al</i> ^[54]	196 ± 28	187 ± 23	248 ± 94	576 ± 176	5%	3%	9.3 ± 3.7	12.1 ± 3.6
Wang <i>et al</i> ^[55]	145 ± 27	156 ± 32	264 ± 89	673 ± 145	10%	7%	10.6 ± 2.5	14.6 ± 3.8
Zairi <i>et al</i> ^[56]	170	186	148	486	3%	3%	4.5	5.5
Seng <i>et al</i> ^[57]	185 ± 9	166 ± 7	127 ± 46	405 ± 80	-	-	-	-
Pelton <i>et al</i> ^[58]	112 ± 33	185 ± 34	125 ± 76	275 ± 99	-	-	2.0 ± 0.7	3.0 ± 1.1
Singh <i>et al</i> ^[59]	116 ± 28	186 ± 31	124 ± 92	380 ± 191	-	-	2.3 ± 1.2	2.9 ± 1.1
Brodano <i>et al</i> ^[60]	144	102	230	620	3%	9%	4.1	7.4
Zou <i>et al</i> ^[61]	150 ± 41	175 ± 37	131 ± 74	318 ± 177	0%	0%	7.5 ± 2.7	9.3 ± 4.2
Peng <i>et al</i> ^[62]	216	171	150	681	-	-	4.0	6.7
Archavlis <i>et al</i> ^[63]	220 ± 48	190 ± 65	185 ± 140	255 ± 468	13%	4%	7.0	11.0
Dhall <i>et al</i> ^[64]	199	237	194	505	0%	5%	3.0	5.5
Schizas <i>et al</i> ^[65]	-	-	456	961	17%	6%	6.1	8.2
Adogwa <i>et al</i> ^[66]	300	210	200	295	0%	0%	3.0	5.0
Niesche <i>et al</i> ^[67]	140	130	150	380	0%	11%	5.0	10.0
Lau <i>et al</i> ^[68]	390	365	467	566	0%	0%	5.0	6.2

RCT: Randomized controlled trial; IRCT: Incomplete randomized controlled trial; SD: Standard deviation; MIS: Minimally invasive.

invasive approaches, over time, as younger surgeons become more proficient with MIS techniques, operative times will likely decrease and we could see a decrease in the difference in operative times between MIS and open lumbar decompressions.

This study also found that patients undergoing MIS decompression were found to have less postoperative pain, lower perioperative transfusion rates and decreased LOS compared to those who underwent open decompression. These findings are not surprising given that the MIS technique results in significantly smaller surgical incisions, is muscle sparing and bypasses the need for extensive paraspinal and soft tissue stripping.

In terms of perioperative outcomes following lumbar decompressive laminectomy, there is a state of equipoise between MIS and open approaches, with neither technique clearly superior. At this time, individual patient and surgeon preferences are appropriate to guide decision making until further evidence becomes available.

Lumbar interbody fusion has become a popular surgical tool in the treatment of a wide variety of lumbar pathology including degenerative disc disease, recurrent lumbar herniation, spondylolisthesis and complex lumbar stenosis^[69]. Currently popular approaches for achieving lumbar interbody fusion include the open anterior (ALIF) and MIS lateral (DLIF and XLIF) retroperitoneal approaches and the open and MIS posterior transforaminal (TLIF) approaches. While each one of

these approaches utilizes a different anatomic corridor, they all have a common end goal of achieving interbody fusion. However, approach specific limitations and direct and indirect complications make each one of these approaches unique and worthy of comparison.

There are currently no randomized trials comparing ALIF and DLIF/XLIF in the literature. There is a wide variation in the reported outcomes data between MIS and open approaches for ALIF and DLIF/XLIF and this heterogeneity does not allow for meta-analysis of the current literature due to the high risk of potential bias. Furthermore, all of the currently available literature on lateral approaches involves the use of a single commercial system (XLIF, NuVasive, San Diego, California, United States) while there are currently many different commercial systems in use across the country.

There is currently a dearth of high quality literature on MIS alternatives (DLIF, XLIF) to ALIF. Although there appears to be no evidence of inferiority, these approaches should be considered investigational by surgeons and patients until better quality studies justify evidence-based statements of non-inferiority.

There have been several high quality studies in the literature comparing MIS TLIF and open TLIF surgeries. In terms of EBL, LOS, transfusion need and perioperative pain, the current data all favor MIS TLIF.

Although EBL differences across randomized studies did not reach clinically meaningful levels of ≥ 750 mL, one of the randomized studies did find a significantly

reduced transfusion need between MIS and open TLIF^[44].

LOS was found to be significantly reduced in MIS TLIF by almost three days, however all of the studies originated from Chinese hospitals. LOS effect estimates, however, may not be applicable across countries, as different health systems use different discharge qualifications and have appreciably different LOS for similar procedures.

There are no outcome categories reported that identify MIS approaches to be significantly worse. Based on current data for perioperative outcomes, it appears that MIS approaches are superior to open approaches in TLIF.

Currently, there exists a wide variation in reported perioperative outcomes in both open and MIS lumbar spine surgery in the literature. Although multiple different outcomes are being reported there exists a lack of defined criteria for many of the reported outcomes such as hospital LOS, postoperative narcotic utilization and need for perioperative transfusion. Furthermore, none of the currently published literature used independent observers when reporting outcomes such as EBL and neurologic complication, leading to the risk of complication under-reporting due to the self-reporting nature of the outcomes data collection.

The current evidence does not clearly support superior perioperative outcomes for patients receiving minimally invasive spine surgery across all modalities. Based on perioperative outcomes data, we recommend a MIS approach to TLIF surgeries. MIS and open approaches can be chosen based on patient and surgeon preference when performing a laminectomy. Regarding lateral approach surgeries, there is insufficient evidence to find non-inferior perioperative outcomes at this time.

COMMENTS

Background

The advents of the surgical microscope and advances in technology have led to an increase in popularity in minimally invasive spine surgery. While prior studies have compared minimally invasive spine surgery to the traditional open spine surgery in terms of long-term outcomes, no study has compared the two techniques in terms of perioperative outcomes.

Research frontiers

Outcomes research in spine surgery has become a very important and highly prioritized area of research with the primary focus of minimizing cost while maximizing outcome.

Innovations and breakthroughs

This is the first study evaluating perioperative outcomes, comparing minimally invasive approaches and techniques vs open surgery in the treatment of degenerative lumbar spine disease.

Applications

While minimally invasive spine surgery has shown to have similar long-term outcomes to open spine surgery, it is important to evaluate perioperative outcomes of minimally invasive techniques to the standard open surgery in order to fully determine the advantages or disadvantages of the new technology compared to the gold standard.

Peer-review

The authors present us a comprehensive systematic review regarding short term outcomes following minimally invasive lumbar spine surgery. This topic is of interest and of novelty.

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