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MINIMALLY INVASIVE SPINE SURGERY (W HSU, SECTION EDITOR)

A Systematic Review of Complications Following Minimally Invasive Spine Surgery Including Transforaminal Lumbar Interbody Fusion

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Abstract

Purpose of Review To assess complications after minimally invasive spinal surgeries including transforaminal lumbar interbody fusion (MI-TLIF) by reviewing the most recent literature.

Recent Findings Current literature demonstrates that minimally invasive surgery (MIS) in spine has improved clinical outcomes and reduced complications when compared with open spinal procedures. Recent studies describing MI-TLIF primarily for degenerative disk disease, spondylolisthesis, and vertebral canal stenosis cite over 89 discrete complications, with the most common being radiculitis (ranging from 2.8 to 57.1%), screw malposition (0.3–12.7%), and incidental durotomy (0.3–8.6%).

Summary Minimally invasive spine surgery has a distinct set of complications in comparison with other spinal procedures. These complications vary based on the exact MIS procedure and indication. The most frequently documented MI-TLIF complications in current published literature were radiculitis, screw malposition, and incidental durotomy.

Keywords Minimally invasive · Spine · Transforaminal lumbar interbody fusion (TLIF) · Complications · Systematic review

Introduction

In the USA, around 80% of the population will experience back pain during their lifetime [1], many of whom will require surgical intervention. Over the past 30 years, minimally invasive surgery (MIS) has emerged as a leading treatment choice for spinal ailments. These techniques caused a major paradigm shift in spine surgery by proving that decreased operating exposure can translate to clinical benefits, such as decreased rates of CSF leaks, infection, and length of stay [2, 3, 4••].

This article is part of the Topical Collection on *Minimally Invasive Spine Surgery*

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Minimally invasive lumbar spine procedures are used for discectomy, spinal decompression, posterior lumbar interbody fusion (MI-PLIF), and transforaminal lumbar interbody fusion (MI-TLIF). Each of these operations is associated with distinct complication profiles. The complication rate for discectomy procedures is around 1.5% and includes dural tears, nerve root injury, and discitis [5]. Following decompression, common complications include dural tears and delayed pseudomeningocele formation [6, 7]. A review found complication rates ranged from 0 to 33.3% for MI-TLIF and 1.6–16.7% for MI-PLIF with radiculopathy and cerebrospinal fluid leakage being the most common etiologies [8].

Not only is there variation in complication rates among different minimally invasive spine procedures, but there also is a wide range in complication profiles based on the specific surgical approach and indication. Despite leading to decreased complication rates, there are unique complications after minimally invasive spinal procedures, especially MI-TLIF. By understanding the complications associated with once novel, and now commonplace, minimally invasive spinal techniques, surgeons can better prepare for these complications and address them when they occur.

Methods

A systematic review in PubMed was performed to identify all articles published from January 2002 to January 2019 for patients undergoing MI-TLIF. The search terms included MeSH terms for minimally invasive surgical procedures and transforaminal lumbar interbody fusion. Abstracts were screened for the following inclusion criteria: English language, patients who underwent MI-TLIF procedure(s), with sample size of at least 100 subjects. Exclusion criteria included: studies involving non-surgical patients, abstracts, case reports, meta-analyses, literature reviews, technical notes, and studies that did not document complications. Among articles meeting inclusion criteria, article information and data on complication types, rates, and outcomes were summarized. The search was independently replicated by internal author (B.H.) to ensure accuracy.

Results

Review of the literature for MI-TLIF studies resulted in 31 articles published from 2008 to 2019 meeting eligibility criteria (Fig. 1). Indications for MI-TLIF included degenerative disk disease, spondylolisthesis, and vertebral canal stenosis as the indicators for surgery. These studies included 12 retrospective single-arm studies, 8 retrospective comparative studies, 3 prospective comparative studies, and 3 prospective single-arm studies. In total, 6699 patients undergoing MI-TLIF were included in the final 31 studies.

Of the 31 articles, 26 articles specified the complications following MI-TLIF (Table 1). There were five articles that met inclusion criteria but did not report complications [35–39]. The most common complication cited after MI-TLIF surgery was radiculitis, with a range between rates of 2.8 and 57.1%. The second most common complication documented in the literature was screw malposition, ranging between rates of 0.3 and 12.7%. The third most common complication was incidental durotomy, with a range between 0.3 and 8.6%. Six articles specifically focused on one type of complication, including graft extrusion, incidental durotomy, pedicle breach, cage subsidence, superior facet violation, and screw malposition. These articles did not document data on other complications. In total, the studies referenced 89 (range 1 to 21) discrete complications for MI-TLIF.

Discussion

Minimally invasive spine surgery has shown favorable clinical outcomes when compared with open procedure [2, 3, 4••, 40, 41]. Minimally invasive spine surgery has been shown to have decreased blood loss, hospital stay, medical and surgical complications, and equivalent patient satisfaction rates as traditional methods [42]. Although minimally invasive spine surgery has a favorable complication profile when compared with open methods, extensive studies continue to reveal that these newer techniques have distinct complications. In the review of the literature, 31 articles describing MI-TLIF were identified but only 26 articles reported complications. The top three complication categories among large sample size MI-TLIF studies were radiculitis, screw malposition, and incidental durotomy.

Open TLIF is progressively being replaced with minimally invasive techniques. First described in 2002 by Foley and Gupta, MI-TLIF was reported to have decreased paraspinous tissue damage, without weakening the effectiveness of the spinal fusion [43]. Meta-analyses comparing minimally invasive and open TLIF have documented decreased blood loss and quicker rehabilitation in the minimally invasive cohorts. The improved timing to postoperative ambulation in turn results in decreased complication rates, decreased length of stay, and ultimately decreased healthcare costs [4••, 40, 41]. For these reasons, trends favor minimally invasive approaches for lumbar fusion. Due to smaller surgical window and introduction of novel techniques, common complications include neurological deficits, cerebrospinal fluid leaks, and misplaced hardware [44]. This systematic review corroborates previous published common MI-TLIF complications. Cerebrospinal fluid leaks have been shown to occur less often in minimally invasive spine surgery when compared with open surgery, and when they do occur, CSF leaks in open surgical procedures result in higher rates of lumbar drain placement and surgical intervention [26]. There are some unique but uncommon complications that are becoming more prevalent with the use of minimally invasive spine surgical approaches. One such complication is a Kirschner wire (K-wire) fracture during MI-TLIF. Although rare, with one study revealing an incidence as low as 1.2%, K-wire fractures pose a potential risk for migration and further complications [45]. There are limited data on K-wire fractures, often because this might go undocumented and is thus underreported in the literature on complications following minimally invasive spine procedures.

Additionally, specific patient characteristics might influence the rates and variability of complications following spine surgery including body mass and age. Obesity has been associated with greater rates of perioperative complications during thoracic and lumbar fusion [46]. However, studies investigating outcomes in obese populations compared with normal weight populations undergoing MI-TLIF have found no significant difference in complications [28], with some studies suggesting decreased complications in obese patients undergoing minimally invasive surgery compared with open TLIF [47•]. A retrospective analysis of elderly patients revealed a complication rate of 11.1% and all complications resolving by

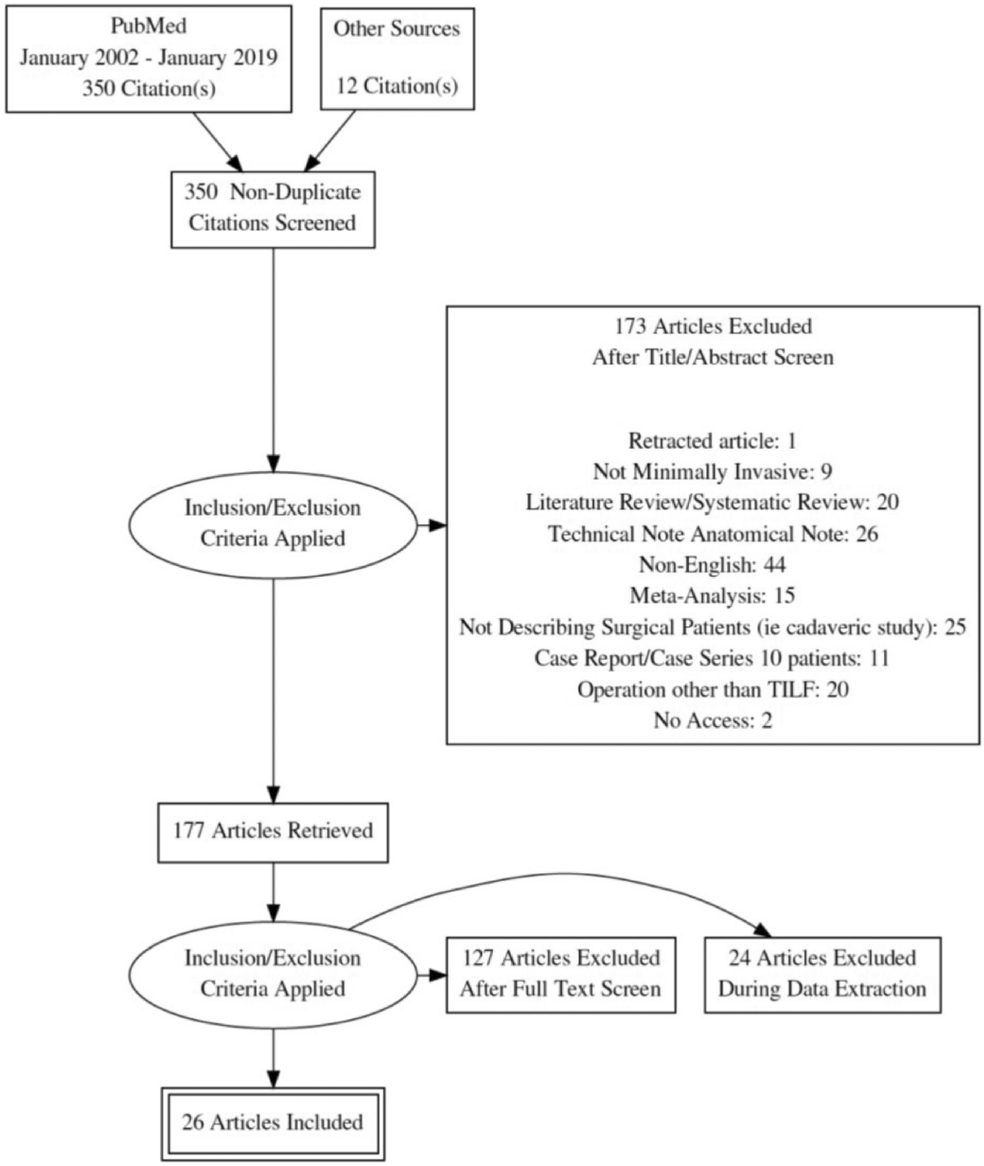

Fig. 1 PRISMA systematic review flow chart. PRISMA flow chart displaying the systematic review of minimally invasive transforaminal lumbar interbody fusion (MI-TLIF)

the 1-year follow-up, suggesting minimally invasive spinal surgery may be safe in elderly populations [48].

Minimally invasive spine surgery for adult spinal deformity also is an important subgroup with a different complication profile. Open surgery for adult scoliosis has been described as having very high complication rates, up to 66% [49]. Minimally invasive lateral transpsoas surgery for adult degenerative scoliosis (DS), however, has been shown to have significantly decreased complications when compared with open surgery [50, 51]. In one study investigating concave versus convex approaches for minimally invasive lateral lumbar interbody fusions for thoracolumbar DS, complications occurred approximately 25% of the time and reoperations were required in 18.8% of patients, with higher complication risk in the concave approach [19]. Although minimally invasive surgery using a lateral approach has been shown to be effective for both coronal and sagittal spine realignment, cage subsidence remains a serious complication [52].

Minimally invasive spinal decompression (MISD) has been shown to have equivalent efficacy to traditional, open decompression methods, with decreased pain, recovery time, and opioid use [53, 54]. Rahman et al. compared open decompressive laminectomy with minimally invasive lumbar laminectomy for lumbar stenosis, finding complication rates of 16.1% in the open group compared with 7.9% in the minimally invasive cohort [53]. A systematic review describing MISD for degenerative spondylolisthesis found an overall complication rate of 1.6% and an overall reoperation rate of 4.5% [55]. Another systematic review exploring minimally invasive discectomy versus microdiscectomy and open discectomy in lumbar disc herniation cases found lower rates of surgical site infections and urinary tract infections, yet

Table 1 Included study characteristics and corresponding complication data for MI-TLIF

Author	Year	Design	F/U	MI-TLIF patient sample	Complication	N	%	Recommended treatment	Resolution of complication on follow-up
Senker et al. [9]	2018	Retrospective, single arm	1 mo to 1 y	229 patients	Postoperative neurologic deficit	1	0.4	NR	NR
					Incorrect fixation (rod)	2	0.9	NR	NR
					Screw loosening (osteoporotic)	2	0.9	NR	NR
					Dermal excoriation due to surgical draping	1	0.4	NR	NR
					Activated omarthrosis by surgery storage	1	0.4	NR	NR
					Adjacent segment disease	1	0.4	NR	NR
					Urinary tract infection	2	0.9	NR	NR
					Hematoma (spinal epidural, POD 4)	1	0.4	Revision surgery	NR
					Screw pullout (osteoporotic)	1	0.4	Cement screws (after 2 months)	NR
					Screw malposition	1	0.4	Revision surgery (day 3)	NR
					Vertebral canal narrowing (POD 1, bony fragment)	1	0.4	Revision surgery (day 1)	NR
					Vertebral canal narrowing (POD 16, pedicle fracture)	1	0.4	Revision surgery day 16	NR
					Mechanical dislocation of proximal fusion system	1	0.4	Revision surgery, 1 month	NR
					Cerebrospinal fluid leak	3	1.3	NR	NR
Fan et al. [10]	2017	Prospective, comparative	NR	126 patients, comparing localization systems in overweight/obese (BMI ≥ 24) patients	Cerebrospinal fluid leak (intraoperatively)	2	1.6	Conservative treatment	NR
					Surgical site infection	2	1.6	Antibiotics	NR
					Guide wire breakage	1	0.8	Broken wire removed intra-operatively	Resolved
Singh et al. [11]	2017	Retrospective, comparative	6–12 wks.	139 patients comparing post-op analgesia	Unspecified: either incidental durotomy, epidural hematoma, ligament tear, perioperative fracture, vascular injury, hemorrhage	1	0.7	NR	NR
Li et al. [12]	2017	Prospective, comparative	30.3 mo mean	103 patients using tunnel technique, compared to open TLIF	Pneumonia	1	1.0	Not reported	NR
					Screw malposition	3	2.9	Asymptomatic, no replacement needed	NR
Liu and Zhou [13]	2017	Prospective, comparative	46.5 mean	192 patients compared to PELD	Incidental durotomy; cerebrospinal fluid leak (lasted 3–5 days post-op)	6	3.1	overlying fascia closed tightly, supine bed rest few days post-operatively	Resolved within 1 week; CSF leakage lasted 3–5 days
					Adjacent segment disease	5	2.6	NR	NR
					Surgical site infection (deep)	1	0.5	Surgery	Resolved
Tay et al. [14]	2016	Retrospective, comparative	2.71–2.88 y mean	230 patients comparing outcomes in patients with and without mild lumbar scoliosis	Graft site infection (iliac crest);	1	0.4	Exploration, debridement, oral antibiotics,	Resolved
					Non-union; cage retropulsion	1	0.4	revision 4 y later	Poor outcome
					Screw malposition; pneumonia; cage migration	1	0.4	Revision surgery (2 wks), pneumonia resolved with IV antibiotics	Resolved
						1	0.4		Resolved
					Broken cage (intraoperatively)	1	0.4	Cage could not be removed	Resolved
					Graft site infection (iliac crest);	1	0.4	debridement, oral antibiotics;	Resolved
					Incidental durotomy	1	0.4		Resolved
					Screw malposition (medial R L5 pedicle);	2	0.9		Asymptomatic
					cage migration	7	3.0		Asymptomatic

Table 1 (continued)

Author	Year	Design	F/U	MI-TLIF patient sample	Complication	*N*	%	Recommended treatment	Resolution of complication on follow-up
					Urinary tract infection	1	0.4	dural tear repaired with collagen	Asymptomatic
					Skin urticaria	1	0.4	matrix, fibrin glue	Asymptomatic
					Cage subsidence; progression of	1	0.4	intraoperatively	Asymptomatic
					spondylolisthesis	1	0.4	Revision MIS surgery (2 wks.)	Asymptomatic
					Cage subsidence	1	0.4	Conservative treatment	No improvement; poor outcome
					Progression of spondylolisthesis	1	0.4	Conservative treatment	
					Broken screw (left L5 pedicle)	1	0.4	No intervention	Resolved
					Screw loosening (right L5 pedicle)	3	1.3	No intervention	Asymptomatic
					Screw malposition	1	0.4	No intervention	Asymptomatic
					Radiculopathy (persistent, left L5)	1	0.4	No intervention	Asymptomatic
					Non-union			No intervention	Asymptomatic
					Cage subsidence; broken screw			No intervention	
					(right S1 pedicle)			Left L4–L5 pedicle screws, rod	
					Cage migration			removed	
					Cage migration; progression of			Revision MIS instrumentation with	
					spondylolisthesis			bone grafting 2 y later	
					Cage subsidence; screw loosening			No intervention	
					(B/L L4 pedicle)			No intervention	
								No intervention	
								No intervention	
Bakhsheshian et al. [15]	2016	Retrospective, single arm	13.6 mo (8.8) mean (SD)	513 patients focused on graft extrusions	Graft extrusion	4	0.8	2 patients required revision surgery	NR
					Graft extrusion; hematoma (spinal epidural)	1	0.2	for cage migration, 2 patients had no clinical consequences	NR
								Revision surgery POD 3	
Wong et al. [16••]	2015	Prospective, single arm	13.6 mo (8.8) mean (SD)	513 patients	Incidental durotomy	26	5.1	Flat bed rest overnight	Resolved
					Instrumentation failure	11	2.1	Revision surgery (2), k wire	Resolved
					Urinary retention	7	1.4	retrieved (5),	Resolved
					Pulmonary embolism	5	1.0	intraoperative repositioning and	Resolved (1 death)
					Neurological deficit	4	0.8	removal of k wire fragment (1)	2 residual weakness,
					Ileus	4	0.8	No intervention	2 resolved
					Hematoma	4	0.8	Anticoagulation therapy	Resolved
					Deep vein thrombosis	2	0.4	Physical therapy	Resolved
					Surgical site infection	1	0.2	No intervention	Resolved
								Reoperation for evacuation	NR
								(for the 3 patients who had continued radicular sx)	
								Anticoagulation therapy	
								NR	
Giorgi et al. [17]	2015	Prospective, single arm	1y	182 patients	Non-union	2	1.1	Revision surgery	NR
					Screw malposition (symptomatic)	5	2.7	Revision surgery	NR
					Non-union	2	1.1	Revision surgery	NR
					Surgical site infection	1	0.5	Revision surgery	NR
					Bleeding (unspecified)	1	0.5	Revision surgery	NR

Table 1 (continued)

Author	Year	Design	F/U	MI-TLIF patient sample	Complication	*N*	%	Recommended treatment	Resolution of complication on follow-up
					Other complications without revision	5	2.7	No intervention	NR
Klingler et al. [18]	2015	Retrospective, single arm	NR	372 patients focus on incidental durotomies	Incidental durotomy	32	8.6	Conservative treatment	Resolved
					There were 3 additional complications noted, but only within the accidental durotomy group, so excluded				
Scheer et al. [19]	2015	Retrospective, comparative	1 y	282 patients comparing in situ arthrodesis vs reduction	C. difficile diarrhea	1	0.4	NR	NR
					Pneumonia	2	0.7	NR	NR
					Cholecystitis	1	0.4	NR	NR
					Atrial flutter	1	0.4	NR	NR
					Acute mental status change	2	0.7	NR	NR
					Stroke	2	0.7	NR	NR
					Urinary retention	3	1.1	NR	NR
					Deep vein thrombosis	1	0.4	NR	NR
					Ileus	1	0.4	NR	NR
					Urinary tract infection	1	0.4	NR	NR
					Pulmonary embolism	2	0.7	NR	NR
					Incarcerated hernia	1	0.4	NR	NR
					Cage retropulsion	1	0.4	NR	NR
					Cage expulsion	1	0.4	NR	NR
					Extruded interbody cage	1	0.4	NR	NR
					Cerebrospinal fluid leak	22	7.8	NR	NR
					Kwire fracture	2	0.7	NR	NR
					Hematoma (wound)	2	0.7	NR	NR
					Surgical site infection	1	0.4	NR	NR
					Neurologic deficit (somatosensory evoked potentials)	4	1.4	NR	NR
						2	0.7	NR	NR
					Neurologic deficit (loss motor evoked potentials)				
Park et al. [20]	2015	Retrospective, single arm	NR	124 patients	Temporary postoperative neuralgia	3	2.4	NR	Resolved
					Deep wound infection	2	1.6	Reoperation	Resolved
					Screw malposition	2	1.6	Reoperation	Resolved
					Cage migration	2	1.6	Reoperation	(one pseudoarthrosis)
					Incidental durotomy	1	0.8	Repaired	Resolved
					Graft extrusion	1	0.8	Reoperation	Resolved
									Resolved
Eckman et al. [21]	2014	Retrospective, comparative	3 mo	1005 patients 1114 procedures	Transfusions	7	0.7	NR	NR
					Infection (unspecified)	1	0.1	NR	NR
					Revision surgery (unspecified)	33	3.3	NR	NR
Park et al. [22]	2014	Retrospective, single arm	5 y	124 patients	Incidental durotomy	1	0.8	NR	NR
					Screw malposition	2	1.6	Secondary surgery (2)	NR
					Cage migration	2	1.6	Secondary surgery (2)	NR
					Graft extrusion	1	0.8	Secondary surgery (1)	NR
					Temporary postoperative neuralgia	3	2.4	NR	NR

Table 1 (continued)

Author	Year	Design	F/U	MI-TLIF patient sample	Complication	N	%	Recommended treatment	Resolution of complication on follow-up
					Deep wound infection	2	1.6	Secondary surgery (2)	NR
					Pseudoarthrosis	41	33.1	secondary surgery,	NR
					Adjacent segment disease	35	28.2	for pseudoarthrosis and ASD (1)	NR
					(symptomatic)	25	20.2	Secondary surgery (7)	NR
					Spinal stenosis (including	5	4	Secondary surgery (7)	NR
					foraminal stenosis)	3	2.4	NR	NR
					Vertebral compression fracture	2	1.6	NR	NR
					Herniated lumbar disc			NR	
					Spondylolisthesis				
Perez-Cruet et al. [23]	2014	Prospective, single arm	47 mo mean	304 patients	Screw malposition	1	0.3	Return to operating room	NR
					Incidental durotomy	1	0.3	Conversion to open TLIF	NR
					Interbody cage retropulsion	3	1	Reoperation	NR
					Bleeding (intraoperative hemorrhage	1	0.3	NR	NR
					> 500 mL)	1	0.3	NR	NR
					Broken screw (7mo. post-operative)	17	5.6	NR	NR
					Urinary retention	11	3.6	NR	NR
					Surgical site infection (superficial)	8	2.6	NR	NR
					Atelectasis	3	1	NR	NR
					Pneumonia	2	0.7	NR	NR
					Urinary tract infection	1	0.3	NR	NR
					Deep vein thrombosis				
Smith et al. [24]	2014	Prospective, single arm	9 mo mean	151 patients focus on pedicle breach after percutaneous screw fixation	Transient nerve root complication	2	1.3	No intervention	Resolved
Wang et al. [25]	2014	Retrospective, single arm	1 mo	204 patients	Myocardial infarction	1	0.5	NR	NR
					Stroke	1	0.5	NR	NR
					Gastric bleeding	3	1.5	NR	NR
					Pneumonia	2	1	NR	NR
					Urinary retention	15	7.4	NR	NR
					Urinary tract infection	6	2.9	NR	NR
					Hardware malposition	3	1.5	NR	Permanent neurologic
					Hematoma (local epidural)	2	1	Reoperation within 1 week	damage (1), resolved
					Graft dislodgement	1	0.5	Reoperation within 1 week	(2)
					Manipulative error	1	0.5	No intervention	Resolved
					Nerve impingement	1	0.5	Reoperation within 1 week	Resolved
					Surgical site infection (superficial)	5	2.5	NR	Permanent neurologic
					Incidental durotomy	10	4.9	Fascia closed tightly over	damage
					Neurologic deficit (leg sensory	24	11.8	No intervention	Resolved
					disturbance)				NR
									Resolved
									NR
	2014		46 mo			8	5.6	NR	NR

Table 1 (continued)

Author	Year	Design	F/U	MI-TLIF patient sample	Complication	*N*	%	Recommended treatment	Resolution of complication on follow-up
Wong et al. [26]		Retrospective, comparative		144 patients compared with open TLIF	Neurologic radiculitis; neurologic	4	2.8	NR	NR
					deficit (immediate postoperative)	5	3.5	NR	NR
					Neurologic radiculitis; neurologic	1	0.7	NR	NR
					deficit (> 48 h)	7	4.9	NR	NR
					Cerebrospinal fluid leaks	2	1.4	Revision surgery	NR
					Vascular or abdominal injury	1	0.7	Revision surgery	NR
					Persistent stenosis (symptomatic)	3	2.1	NR	NR
					Screw malposition	3	2.1	NR	NR
					Cage migration	3	2.1	NR	NR
					Transfusion (postoperative)	6	4.2	NR	NR
					Respiratory infection	3	2.1	NR	NR
					Urinary tract infection	2	1.4	NR	NR
					Surgical site infection (superficial)	12	8.3	Revision surgery	NR
					Hematoma (diagnosed postoperatively)	2	1.4	Revision surgery	NR
					Deep vein thrombosis (symptomatic)	3	2.1	Revision surgery	NR
					Revision surgery (4 y, overall)	1	0.7	Reoperation	NR
					Repeat decompression	3	2.1	NR	NR
					Revision surgery (hardware issues)	3	2.1	NR	NR
					Vascular or abdominal repair				
					Pseudarthrosis				
					Adjacent-level degeneration (new)				
Kim et al. [27]	2013	Retrospective, single arm	2 y	104 patients focus on cage subsidence	Cage subsidence	22	21.2	NR	NR
					< 2 mm	10	9.6	NR	NR
					2–4 mm	8	7.7	NR	NR
					< 4 mm				
Lau et al. [28]	2013	Retrospective, comparative	NR	142 patients focus on superior facet violation; comparing open vs MI-TLIF, imaging technique	Superior facet violation	9	6.3	NA	NA
Silva et al. [29]	2013	Retrospective, comparative	33 mo mean	138 patients	Incidental durotomy	8	5.8	Corrected intraoperatively	Resolved; persistent
					Urinary retention; perineal hypesthesia	1	0.7	convert to open procedure (1)	neurogenic bladder,
					Radiculopathy (severe, transient, postoperative)	3	2.2	NR	perineal hypesthesia (1)
					Surgical site infection (superficial)	2	1.5	NR	NR
					Radiculopathy (motor, persistent)	1	0.7	NR	NR
					Screw malposition	1	0.7	NR	NR
					Hematoma (extradural)	1	0.7	Revision	NR
					Myocardial infarction	1	0.7	Reintervention	NR
								NR	NR
									NR
Singh et al. [30]	2013	Retrospective, single arm	1 y	610 patients 573 followed up	Radiculitis	327	57.1	Medrol dose pack 1 month	Resolved (except cases
					Incidental durotomy	23	4.0	NR	that underwent
					Surgical site infection	3	0.5	Irrigation and debridement (1)	revision surgery
					Neuroforaminal bone growth;	10	1.7	Revision surgery (3 underwent	before)

Table 1 (continued)

Author	Year	Design	F/U	MI-TLIF patient sample	Complication	*N*	%	Recommended treatment	Resolution of complication on follow-up
					osteolysis; cage migration	39	6.8	two revisions)	NR
					Revision surgery (other)	10	1.7	NR	NR
					Bone overgrowth; nerve impingement;	2	0.3	NR	NR
					radiculopathy	1	0.2	Revision surgery	NR
					Cage migration; osteolysis	39	6.8	NR	NR
					(in 2 of the above bone			Revision arthrodesis	NR
					overgrowth patients)				NR
					Calcified fluid collection				NR
					Pseudoarthrosis				
Kim et al. [31]	2011	Retrospective, single arm	NR	110 patients focus on pedicle malposition screws (% reflects screw malposition per 488 total screws placed)	Screw malposition (cortical encroachment) Screw malposition (Frank penetration) Minor (< 2 mm) Moderate (≥ 2, < 4 mm) Severe (≥ 4 mm)	61* 46* 7* 1*	12.5* 9.4* 1.4* 0.2*	NR NR 2 needed revision	NR NR Of revision patients: 1 residual neurological deficit, 1 resolved
Rouben et al. [32]	2011	Prospective, single arm	49 mo	169 patients	Screw malposition (painful pedicle screws)	6	3.6	Revision needed, 3 needed fusion with adjacent level due to pain	Resolved
					Pseudarthrosis	1	0.6	NR	Resolved
					Infection (staph)	1	0.6	Revision surgery	Resolved
					Broken pedicles (L4, postoperative fall)	1	0.6	Revision surgery	Resolved
Matsumoto et al. [33]	2010	Retrospective, comparative	NR	379 patients combined TLIF and PLIF, not specified	Dural injury	1	0.3	Specific treatment not documented	NR
Rosen et al. [34]	2008	Prospective, single arm	14.8 mo mean	110 patients	Urinary retention	4	3.6	NR	NR
					Lower extremity weakness	1	0.9	NR	NR
					Delirium	5	4.5	NR	NR
					Radiculopathy (postoperative)	5	4.5	NR	NR
					Positioning injury	1	0.9	NR	NR
					Incidental durotomy	2	1.8	NR	NR
					Surgical site infection (superficial)	1	0.9	NR	NR
					Congestive heart failure exacerbation	1	0.9	NR	NR
					Hypertension	2	1.8	NR	NR
					Hypotension	2	1.8	NR	NR
					Ileus	1	0.9	NR	NR

F/U, follow-up time period; *NR*, not reported; *y*, year; *mo*, months; *wks*, weeks; *b/l*, bilateral; *post-op*, postoperative; *sx*, symptoms; *PLIF*, posterior lumbar interbody fusion; *TLIF*, transforaminal lumbar interbody fusion; *POD*, postoperative day; *BMI*, body mass index; *PELD*, percutaneous endoscopic lumbar discectomy; *ASD*, adjacent segment disease; *kwire*, kirschner wire

*Values are represented as the number and the percentage of misplaced screws ($n = 488$)

higher rates of rehospitalization for recurrent disc herniation [56].

Recently, minimally invasive spine surgery has extended beyond just novel methods for elective procedures to traumatic injuries. Percutaneous pedicle screw fixation (PPSF) has been shown to be a satisfactory management method for traumatic spine injuries, such as flexion-distraction injuries. Studies comparing open pedicle screw fixation and posterolateral fusion to minimally invasive PPSF in thoracolumbar flexion-distraction injuries found that the two methods had very similar efficacy, with minimally invasive methods resulting in decreased blood loss and tissue damage [57]. A meta-analysis comparing PPSF with open posterior pedicle screw placement for thoracolumbar fractures favored minimally invasive approaches, documenting decreased postoperative pain, blood loss, operating time, length of stay, and incision time, yet no significant difference in complications [58•, 59]. A large study retrospectively analyzing complication rates after PPSF in 781 patients suffering from thoracolumbar and lumbar fracture reported a complication in 5.9%, with complications such as blood vessel injury and poor vertebral reduction and internal fixation, guide wire breakage, screw breakage, and screw malposition [60]. There were also reported complications of screw malposition, cerebrospinal fluid leakage, guide wire rupture, and infection, similar to other minimally invasive spinal procedures.

Minimally invasive spine surgery techniques have revolutionized the management of common and serious spine pathologies, making surgery safer for many patients. Despite the intricacies of specific complication types and rates among varying minimally invasive spine procedures, all novel minimally invasive techniques share a common theme, in that there is a steep learning curve to mastering these innovative procedures [61]. Despite the need for mastering new procedural skills, minimally invasive spine surgical procedures have still been found to have decreased operation time, length of stay, and blood loss, suggesting that the skills associated with minimally invasive spine surgery require specialized surgical training in order to benefit patients [62].

There are several important limitations for this study. We utilized PubMed as the primary engine and attempted to include broad search terms, but it is possible that we did not identify all articles published meeting inclusion criteria. Additionally, the focus of this study is very narrow, systematically analyzing only articles concerning MI-TLIF among studies with at least 100 subjects. There were varying patient populations within the included articles, such as studies including only obese patients or using a distinct surgical technique, perhaps influencing the observed complication rates. Further systematic review of other minimally invasive spine surgeries will be necessary to better understand complication rates across alternative procedures, diagnoses, and patient populations. Future work should focus on a systematic review of all minimally invasive spinal procedures to optimize patient education and clinical preparation and insight into potential complications following minimally invasive spine surgery.

Conclusion Minimally invasive spine surgery, although proven to have lower complication rates than traditional open methods, continues to have a distinct set of complications. These complications vary based on the exact minimally invasive procedure and indication. The majority of MI-TLIF complications based on current published literature are radiculitis, screw malposition, and incidental durotomy.

Compliance with Ethical Standards

Conflict of Interest Hannah Weiss, Roxanna Garcia, Ben Hopkins, Nathan Shlobin, and Nader Dahdaleh declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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