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Extreme lateral lumbar interbody fusion: Do the cons outweigh the pros?

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Abstract

Background: Major factors prompted the development of minimally invasive (MIS) extreme lateral interbody fusion (XLIF; NuVasive Inc., San Diego, CA, USE) for the thoracic/lumbar spine. These include providing interbody stabilization and indirect neural decompression while avoiding major visceral/vessel injury as seen with anterior lumbar interbody fusion (ALIF), and to avert trauma to paraspinal muscles/facet joints found with transforaminal lumbar interbody fusion (TLIF), posterior lumbar interbody fusion (PLIF), and posterior-lateral fusion techniques (PLF). Although anticipated pros of MIS XLIF included reduced blood loss, operative time, and length of stay (LOS), they also included, higher fusion, and lower infection rates. Unanticipated cons, however, included increased morbidity/mortality rates.

Methods: We assessed the pros and cons (e.g., risks, complications, comparable value/superiority/inferiority, morbidity/mortality) of MIS XLIF vs. ALIF, TLIF, PLIF, and PLF.

Results: Pros of XLIF included various biomechanical and technical surgical advantages, along with multiple cons vs. ALIF, TLIF, PLIF, and PLF. For example, XLIF correlated with a considerably higher frequency of major neurological deficits vs. other constructs; plexus injuries 13.28%, sensory deficits 0–75% (permanent in 62.5%), motor deficits 0.7–33.6%, and anterior thigh pain 12.5–25%. XLIF also disproportionately contributed to other major morbidity/mortality; sympathectomy, major vascular injuries (some life-ending others life-threatening), bowel perforations, and seromas. Furthermore, multiple studies documented no superiority, and the potential inferiority of XLIF vs. ALIF, TLIF, PLIF, and PLF.

Conclusion: Reviewing the pros of XLIF (e.g. radiographic, technical, biomechanical) vs. the cons (inferiority, increased morbidity/mortality) vs. ALIF, TLIF, PLIF, and PLF, we question whether XLIF should remain part of the lumbar spinal surgical armamentarium.

Key Words: ALIF, comparison constructs, extreme lateral interbody fusion, lateral lumbar interbody fusion, minimally invasive surgery, posterior-lateral fusion techniques, posterior lumbar interbody fusion, transforaminal lumbar interbody fusion

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INTRODUCTION

Minimally invasive surgery (MIS) consisting of extreme lateral interbody fusion procedures (XLIF) were devised to afford maximal disc excision and end plate availability for interbody fusion, while providing indirect decompression of the neural elements. Aims of MIS XLIF included avoiding the major visceral/vessel injuries seen with anterior lumbar interbody fusion (ALIF), and trauma to the posterior elements (e.g. paraspinal muscles/facet joints) seen with transforaminal lumbar interbody fusion (TLIF), posterior lumbar interbody fusion (PLIF), and posterolateral fusion (PLF). Although further pros included the reduction of operative time, blood loss, length of stay (LOS), and duration of surgery, with potentially higher fusion and lower infection rates, there were also unanticipated cons of MIS XLIF included a disproportionate increase in the neurological/complications of spinal surgery vs. other constructs; i.e. plexus injuries 13.28%, sensory deficits 0–75% (permanent in 62.5%), motor deficits 0.7–33.6%, and anterior thigh pain 12.5–25%.[9-12] Other general complications of XLIF included; major vascular injuries (e.g., some life-threatening, others life-ending), bowel perforations, sterile seromas, and instrumentation failures.[9-12] Here, we reviewed the pros of XLIF (e.g., radiographic, technical, biomechanical, and potential comparability/superiority) and cons (potential inferiority with increased morbidity/mortality) vs. other procedures (e.g. ALIF, TLIF, PLIF, and PLF) to determine whether XLIF should remain part of the spinal surgical armamentarium.

PROS AND CONS OF XLIF: X-RAY/COMPUTED TOMOGRAPHY (CT) AND BIOMECHANICS

Pros of X-ray/CT documentation of indirect decompression with extreme lateral interbody fusion

Postoperative X-rays and computed tomography (CT) studies documented that MIS XLIF with or without posterior instrumentation provided increased maximal disc removal/end plate availability for interbody fusion while affording indirect decompression of the spinal canal (degenerative stenosis or scoliosis) [Table 1].[8,18,20] When 30 MIS XLIF were performed with posterior instrumentation in adults with degenerative lumbar scoliosis in the series by Caputo *et al*., X-rays showed an increase in neuroforaminal height (80.3%), neuroforaminal width (7.4%), disc height (116.7%), segmental lordosis at L4-L5 (14.1%), and global lordosis (11.5%) [Table 1].[8] For MIS XLIF interbody fusions performed at 43 levels (stand alone for degenerative lumbar stenosis) performed in 21 patients averaging 67.6 years of age in a study by Oliveira *et al*., radiographs documented an increase of 41.9% disc height, 13.5% in foraminal height, 24.7% in foraminal area, and 33.1% in central canal diameter.[20] Utilizing 2-day postoperative CT scans, Malham *et al*. further documented increased postoperative disc height (89%), foraminal height (38%)/area (45.1%) for 52 patients (average age 66.4) undergoing 79-level MIS XLIF.[18] Of interest was the disparity in the percentage of decompression provided by MIS XLIF for degenerative stenosis/scoliosis provided by different X-ray and CT evaluations; disc height on X-rays was 116.7% vs. 89% on CT, foraminal height was 80.3% on X-ray vs. 38% on CT.

Biomechanical pros, cons, and comparability of minimally invasive surgeries (MIS) extreme lateral interbody fusion (XLIF)/lateral lumbar interbody fusion (LLIF) vs. other techniques

Several studies explored the biomechanical pros, cons, and comparability of MIS LLIF/XLIF vs. other procedures (e.g. ALIF, TLIF, PLIF, and PLF) (e.g., greater end plate/disc removal, restoration of sagittal balance and/or lordosis, but early cage settling) [Table 1].[12,22,26,27] Tatsumi *et al*. found that for four fusions (ALIF, PLIF, TLIF, and XLIF) performed in 8 cadavers (24 disc spaces and 48 end plates from L2-L5), MIS XLIF provided the most extensive end plate preparation (58.3%) and disc removal (90%), whereas less disc was removed for the other constructs (e.g. 65% for TLIF, 43% for PLIF, and 40% ALIF groups).[26] Comparing MIS lateral lumbar interbody fusions (LLIF) to ALIF, TLIF, and PLF, Sembrano *et al*. noted on standing pre and 6-week postoperative X-rays (147 patients; 212 levels fused), that all constructs demonstrated comparable improvement in sagittal balance, but that ALIF provided better segmental/general correction.[22] For Tohmeh *et al*., 140 patients undergoing MIS XLIF/pedicle screw fixation at 223 levels (followed for 15.5 postoperative months), despite increases in overall lordosis (4.0 to 8.1) and segmental lordosis (10.7 to 13.7), cage settling (e.g. >1 mm or more) occurred in 20% of patients immediately postoperatively and in 62% of the patients within 1 postoperative year.[27] Although this led to the recommendation to use wider and longer cages, this maneuver would potentially increase the risk of "interbody spacer overhang" and contralateral foraminal nerve root compromise or ligamentous rupture, particularly if the device were placed too anteriorly. Note, Epstein's previous review cited a 45% risk of cage-overhang if MIS XLIF were applied in the anterior 1/3 of the vertebral body.[12]

Pros of bilateral vs. unilateral pedicle screw fixation with minimally invasive surgery (MIS) extreme lateral interbody fusion (XLIF)

Several authors found that supplementing MIS XLIF with unilateral or bilateral pedicle screw fixation both increased lordosis, but bilateral instrumentation provided greater

Table 1: Radiographic (X-ray, MR, CT), cadaveric, and biomechanical considerations for MIS lumbar XLIF

Author reference Year	Surgery Other	Surgery Other	Recommendation Observations	Findings Other	Conclusions Risks Complications Other
Youssef[30] 2010	84 MIS XLIF	Followed average 15.7 months	68 (81%) fused No subsidence CT/Dynamic X-rays	2.4% perioperative complications	6.1% postoperative Complications
Oliveira[20] 2010	21 MIS XLIF X-ray MR Study	21 XLIF 43 levels 47 minute surgery	Improvement MR/X-ray 41.9% disc height 13.5% foraminal height 24.7% foraminal area 33.1% central canal diameter	Average age 67.6 Degenerative lumbar stenosis	Complications 3 (14.3%) iliopsoas weakness 2 Reoperations: (9.5%) posterior decompression/ instrumentation
Isaacs[15] 2010	107 patients MIS XLIF With/without posterior fusion	Degenerative scoliosis	Average age 68 Average 4.4 levels per patient	75.7% of patients, 5.6% had lateral fixation, and 18.7% had stand-alone XLIF	Major complications: 13 (12.1%) 2 (1.9%) medical 12 (11.2%) surgical
Arnold[2] 2012	Review of technique of MIS XLIF	Fluoroscopy to identify mid position of disc	True lateral positioning	Larger implants with XLIF vs. TLIF and PLIF	Complications: neural injuries, psoas weakness, and thigh numbness
Caputo[8] 2013	30 MIS XLIF Degenerative scoliosis	14.3 month follow up Evaluation with X-ray and CT	Improvement Foraminal width 7.4% Disc height 116.7% Lordosis 14.1%	Correction; Cobb angle 72.3% Apical translation 59.7% Foraminal height 80.3%	Complications 11.8 pseudarthrosis 1 lateral hernia 2 ruptures ALL 2 wound breakdown 1 pedicle fracture 1 nonunion secondary fusions
Spivak[24] 2013	Lumbar MIS XLIF	XLIF Retractor Placement	Place XLIF Retractor Anterior Half of Disc	Psoas coverage increased 80–85% from L2-L4	Place retractor in anterior half of disc to avoid neural/ plexus injury
Meredith[19] 2013	18 MIS XLIF Thoracic Thoraco- lumbar	XLIF 32 levels 12 Anterior posterior procedures	Most at thoracolumbar junction Medical complications: 2 pulmonary effusions	Medical complications 2 cardiac arrhythmias 1 death 1 metastatic disease	Surgical complications 2 durotomy 1 infection 1 instrument pull-out
Tohmeh[27] 2014	140 Patients 223 MIS XLIF Levels	Pedicle screw fixation Lateral plating Evaluated cage settling for interbody devices	Followed average 15.5 months At 12 months Disability better 44% Low back pain 49% leg pain 48% QUALY 50%	Cage settling 62% at 1 year Reduced with wider/ longer cages Lateral plates reduced cage settling more the pedicle screws	Increase foraminal height 15.7 to 21.2 mm Disc height 4.6 to 9.4 mm discal lordosis 4 to 8.1 mm segmental lordosis 10.7 to 13.7 mm
Lykissas[17] 2014	6 years MIS XLIF wit BMP (72 patients)	Vs. XLIF without BMP (72 patients)	Long term sensory deficits 29 with vs. 20 without BMP	Persistent motor deficits 35 with vs. 17 without BMP	Anterior thigh/groin pain 8 with vs. 0 without BMP

Contd...

Table 1: Contd...

Author reference Year	Surgery Other	Surgery Other	Recommendation Observations	Findings Other	Conclusions Risks Complications Other
Wang[29] 2014	21 patients over 30 months MIS XLIF alone	No screws Spacers without pedicle screws for adjacent level disease	No infection No trauma No prior pedicle screws 17-1 level 4-2 level XLIF	Patients followed average 23.6 mos. Setting 1.7 mm All fused on CT	Used BMP in all interbody XLIF No major complications 1 delayed reoperation
Malham[18] 2014	52 patients 79 level MIS XLIF	Assess foraminal/ arthrotic facet decompression with CT	Average age 66.4 89% > posterior disc height 38% > foraminal height	45.1%> foraminal area	XLIF significantly indirectly decompressed the neural foramen
Fogel[13] 2014	7 Cadavers MIS XLIF	Models of XLIF at L4-L5 with DS	Combinations of Models with XLIF cages	Lateral plate Unilateral or Bilateral screws	Bilateral pedicle screws most effectively reduced A-P displacement with XLIF cage
Buric[6] 2015	29 Patients MIS XLIF (47 levels)	All prior lumbar surgery DDD SS Average age 59	Average 1.6 level XLIF	Use MR to assess psoas dimensions; determine susceptibility to neural deficits	10 (34%) Postoperative anterior thigh/groin pain (24 Hours postop); 3 most only 1 still symptomatic
Sembrano[22] 2015	MIS LLIF ALIF TLIF PSF	147 Fusions at 212 levels	Overall lumbar lordosis changes: ALiF 4.2 LLIF 2.5 TLIf 2.1 PSF—0.5	No significant changes in adjacent level lordosis except for ALIF	Conclusion: LLIF comparably improved sagittal balance
Alimi[1] 2015	23 MIS XLIF	Treat foraminal stenosis/ ipsilateral radiculopathy with XLIF	61% degenerative scoliosis Prior surgery at same level 43%	91% instrumented fusions	Followed 11 mos (average) Preserved increased ipsilateral foraminal height
Tatsumi[26] 2015	MIS PLIF TLIF XLIF ALIF	Comparison four different minimally invasive approaches to end plate preparation	Cadaveric Study (8) 24 Disc Spaces 48 End plates from L2-L5	Extent of disc removal 90% XLIF TLIF 65% PLIF 43% ALIF 40%	End plate Damage 0% XLIF 48% TLIF
Berjano[4] 2015	MIS XLIF	ALIF Risks Major Vessel Injury	TLIF/PLIF Major Posterior Soft Tissue Disruption	XLIF Risk of L45 plexopathy/ dysesthesias/ Psoas weakness Numbness/hip/ groin pain,	Recommended perioperative steroids to reduce plexus/neural deficits/symptoms
Uribe[28] 2016	19 Study cohorts 720 Patients MIS Surgery	MIS XLIF MIS ALIF MIS PLIF MIS TLIF	Focus: Restoration preservation lumbar lordosis with MIS interbody fusions	Significant gains average lumbar lordosis/segmental lordosis with MIS interbody fusion	MIS surgery improved regional/local segmental alignment

A-P, Anterior-Posterior; DS, Degenerative Spondylolisthesis; DLIF, Direct Lumbar Interbody Fusion; DDD, Degenerative Disc Disease; SS, Spinal Stenosis; XLIF, Extreme Lateral Interbody Fusion; MIS, Minimally Invasive Surgery; PSF, Posterior Spinal Fusion; LLIF, Lateral Lumbar Interbody Fusion; OLIF, Oblique Lateral Interbody Fusion; TH, Thoracic; THL, Thoracolumbar; ALL, Anterior Longitudinal Ligament; MIS, Minimally Invasive Surgery

stabilization [Tables 1 and 2].[1,13,21] When Alimi *et al.* performed MIS XLIF plus unilateral instrumented pedicle/screw fusions (91%) to treat unilateral radiculopathy in 23 patients (91%) (e.g., 61% with degenerative scoliosis and 43% with prior surgery), they effectively successfully resolved radicular complaints and maintained increased unilateral foraminal height for up to 11 ± 3.7 postoperative months.[1] However, when Fogel *et al.* compared the efficacy of MIS XLIF stand alone cages vs. MIS XLIF with varying combinations of lateral plates, unilateral/bilateral pedicle screws, and spinous process plates in 7 cadavers at the L4-L5 level (with/without degenerative spondylolisthesis (DS)), they concluded bilateral pedicle screws provided the greatest stability, while spinous process plates afforded the least.[13] Similarly, Phillips *et al.*, in 2013, found that, for 107 patients (average age 68) undergoing average 3 (1–6 levels) level MIS XLIF with/without pedicle screw/rod fusions for degenerative scoliosis (2-year period), the best radiographic results were achieved utilizing bilateral pedicle screws (e.g. best correctin of the Cobb angle (average 15.2 degrees at 2 years)).[21] Certainly, the majority of surgeons would utilize bilateral pedicle screw fixation if they were utilizing instrumentation to supplement MIS XLIF.

Summary of computed tomography (CT)/X-rays and biomechanics minimally invasive surgery (MIS) extreme lateral interbody fusion (XLIF) pros/cons

Pros for MIS XLIF vs. ALIF, TLIF, PLIF, and PLF included more disc removal/end plate availability for interbody fusion, and greater indirect neural decompression by increasing disc height/foraminal height/area/canal diameter.[8,18,20] Cons, however, included a high risk for neurological injury and general complications, along with graft/cage settling (e.g., 20% immediately, 62% at one year).[12,22,26,27]

CONS OF MINIMALLY INVASIVE SURGERY EXTREME LATERAL INTERBODY FUSION

High complication rate for minimally invasive surgery surgery (MIS) extreme lateral interbody fusion (XLIF) vs. Other minimally invasive surgery constructs (ALIF, TLIF, PLIF, PLF)

Neurological complications of extreme lateral interbody fusion vs. other procedures

Neurological complications frequently followed thoracic and lumbar MIS XLIF vs. other constructs that some preferred to label as "anticipated" risks rather than "complications" [Tables 1 and 2].[4,7,9-11,20] Historically, open spinal procedures (discectomy/laminectomy/with or without fusion) incur a 0–2% incidence of root injuries; their frequency was equal to MIS TLIF (2%), but less than MIS PLIF (7.8%), or MIS ALIF (15.8%), and substantially lower than XLIF (23.8%: sustained root/plexus deficits).[9,10] A focused review of neurological complications for MIS XLIF procedures included; plexus injuries (13.28%), sensory deficits (0–75%: permanent in 62%), 5 motor deficits (0.7–33.6%), and anterior thigh pain (12.5–25%).[11] Oliveira *et al.* found that, in their series of 21 patients undergoing 43-level MIS XLIF alone (degenerative lumbar stenosis), that 3 (14.3%) patients developed new iliopsoas weakness/deficits.[20] Berjano *et al.* took it even a step further, recommending prophylactic preoperative steroids to address their too frequent postoperative plexus injuries that continued to occur despite technical improvements for MIS XLIF approaches.[4] When Caputo *et al.* evaluated the efficacy of 30 MIS XLIF (127 levels; T10-L5 (average 4.2 levels) with ALIF (L5S1; 11 patients)) and pedicle screw/rod fixation, postoperative anterior thigh/pain/numbness was so common that they recommended it no longer be considered a "complication" of MIS XLIF, but rather an "anticipated" risk (e.g. postoperative factors).[7]

Cadaver and magnetic resonance/dynamically-evoked electromyography offer technical improvements for minimally invasive surgery extreme lateral interbody fusion procedures, but neurological deficits persist

Two studies, one performed in cadavers and the other performed utilizing magnetic resonsnce images (MR), sought to limit the common MIS XLIF postoperative lumbar plexus deficits [Table 1].[4,6,9-11,20] Utilizing 12 cadavers and 24 lumbar plexuses/psoas muscle exposures, Spivak *et al.* found the "safe" area to avoid MIS XLIF-related lumbar nerve root/plexus injuries between the L2-L4 levels (most susceptible); it was best to place the retractor in the anterior half of the disc.[24] However, if an interbody MIS XLIF spacer is placed within the anterior one-third of the disc, the risk of contralateral root compromise is reportedly high, and this may, therefore, not be a viable solution.[9,11] When Buric *et al.* carefully studied preoperative MR examinations (e.g., lumbar plexus shape/position) and additionally utilized intraoperative dynamically-evoked electromyography to perform 29 MIS XLIF (average age: 59 years; 1.6 level MIS XLIF at 47 levels; 83% used pedicle screws) between the L2-3 and L4-L5 levels, on postoperative day 1, 10 (34%) patients still had anterior thigh/groin pain.[6]

Fluoroscopy and computed tomography (CT) studies offer technical improvements for minimally invasive surgery (MIS) extreme lateral interbody fusion (XLIF) procedures, but neurological deficits still persist

Utilizing intraoperative X-ray/fluoroscopy in combination with postoperative CT examinations helped guide the performance of thoracic and lumbar MIS XLIF procedures [Table 1].[2,30] Arnold *et al.* utilized intraoperative fluoroscopic guidance to place sequential tubes/dilators for perform MIS XLIF; they recommended utilizing a true lateral position, with incision of the mid or somewhat anterior portion of the disc, but still observed

Table 2: Comparison of safety/efficacy of MIS XLIF/LLIF/DLIF Vs. open/MIS PLIF, TLIF, ALIF, and PLF

Author reference Year	Numbers of Patients	Focus of Surgery	Complications	Complications	XLIF complications
Caputo[7] 2012	30 MIS XLIF with pedicle screws Degenerative Scoliosis	Followed 14.3 months ODI 24.8 to 19 SF-12 not significant VAS 6.8 to 4.6	26.6% complications 2 lateral wound breakdown 1 pedicle T12 fracture 1 non union at L12 (reoperation 13 months) one atrial fibrillation (delay secondary posterior fusion)	Complications 2 iatrogenic anterior longitudinal ligament rupture: 2 Reoperations 1 Anterior L45 plate 1 XLIF lateral place at L34	Anterior thigh pain numbness; "substantial" "did not" consider this a complication; anticipated Resolved at 1 month postoperative
Phillips[21] 2013	Multicenter prospective study 107 MIS XLIF	With Without Pedicle Screws	Followed 2 years Average age 68	Significant improvement ODI VAS SF-36 Mental and physical Health Scales	85% satisfied Claimed low complication rate
Barbagallo[3] 2014	MIS LLIF vs. MIS PLIF and TLIF Safety Efficacy Outcomes	Literature review: Only 6 of 258 studies met inclusion criteria	LLIF resulted in less EBL and mortality vs. PLIF	Insufficient evidence: that LLIF was more effective than PLIF or TLIF No LLIF clinical variables correlated with enhanced outcome	Low quality evidence showing lower complication or Reoperation rate for LLIF
Lee[16] 2014	Modified Mini-Open ALIF	74 patients MIS lateral Sequential tubular dilator Expandable retractor	Simple ALIF 1 level; EBL 61.2 ml/86 min 2 levels 250 ml 106 min 3 levels 250ml 142/8 min	4 levels: 400 ml 190 min Incisions 4l5, 6.3, 8.5, and 10 cm	Complications 2 Retroperitoneal clot 1 pneumonia 3 LS plexus palsy/transient
Talia[25] 2015	Review MIS XLIF TLIF ALIF	Safety Efficacy Benefit	TLIF Reduced retraction Better for revision surgery	ALIF risk of vascular and visceral injury	XLIF risk of neural/plexus injury
Berjano[5] 2015	78 total MIS XLIF	CT documented fusion	Followed average 34.5 months Fusion: 75% autograft 89% calcium triphosphate 83% Attrax TM used	68/78 operated levels fused (87.1%) 10.2% (8 patients) Probably fused	2 (2.6%) pseudarthrosis XLIF
Hartl[14] 2016	Review 24 MIS XLIF Studies 9 MIS ALIF Studies 1 MISXLIF/ALIF	18 or 24 XLIF used IONM	XLIF Complications 16.61% ALIF 26.47%	ALIF Neural complication rate 4.96% Lower	Neural Injury 2X Greater for XLIF 8.92% IONM Lowered XLIF Complication rate (16.34 vs. 21.74%)
Sembrano[23] 2016	55 DS/SS 29 MIS XLIF 26 MIS TLIF	Low grade DS Stenosis (SS)	One or two level Operative times same (XLIF 171 vs. 186 TLIF min) LOS 2 days Lower EBL with XLIF (79% XLIF vs. 27% TLI<100 cc)	Complications Hip flexion weakness 31% XLIF vs. 0% TLIF*8	New sensory changes; resolved 1 year 3 XLIF 2 TLIF

DS, Degenerative Spodylolisthesis; SS, Spinal Stenosis; XLIF, Extreme Lateral Interbody Fusion; TLIF, Transforaminal Lumbar Interbody Fusion; LOS, Length of Stay; EBL, Estimated Blood Loss; PLIF, Posterior Lumbar Interbody Fusion; HO, Heterotopic Ossification; ASD, Adjacent Segment Disease; SiCaP, Silicate Calcium Phosphate; DDD, Degenerative Disc Disease; MIS, Minimally Invasive Surgery

a persistent high rate of " neural injuries, psoas weakness, and thigh numbness."[2] In a series by Youssef *et al.* involving 84 MIS XLIF fusions, 68 (81%) were fused on both postoperative CT and dynamic X-rays; notably, the fusion rate was comparable to fusion rates for MIS ALIF, MIS TLIF, and MIS PLIF.[30] Nevertheless, despite MIS XLIF correlating with shorter operative times, reduced blood loss and shorter length of stay, they resulted in an increased incidence of lumbar plexus deficits. Clearly, the MIS XLIF approach inherently places major neurological structures at risk, and the multiple studies developed to limit these risks have not succeeded.

Neurological complications of minimally invasive surgery surgery (MIS) extreme lateral interbody fusion (XLIF) with bone morphogenetic protein: Reported vs."obfuscated" results

Additional unique complications occurred when bone morphogenetic protein (rhBMP-2) was utilized to supplement MIS XLIF/LLIF constructs [Tables 1 and 2].[5,17,29] In a series by Lykissas *et al.*, over a period of 6 years, MIS LLIF were performed with (rhBMP-2; 72 patients) vs. without rhBMP-2 (72 patients, autograft/allograft).[17] BMP clearly contributed to both short and long-term direct damage to the lumbosacral plexus; long-term sensory deficits were noted in 29 patients who received rh-BMP-2 vs. 20 without; persistent motor deficits were observed in 35 patients with vs. 17 without rh-BMP-2; and anterior thigh/groin pain was observed in 8 patients with vs. 0 without BMP. On the contrary, when Wang *et al.* evaluated the treatment of adjacent segment stenosis in 21 patients (average age 61 following prior anterior or posterior fusions) undergoing 1-2 level MIS XLIF (17, single level, 4, two level; interbody spacers) with BMP without pedicle/screw fixation, CT studies showed a 100% fusion rate and no complications.[29] The total absence of neurological complications and 100% fusion rate were signals in this manuscript that, at best, the documentation was inadequate, and at worst, the data were "obfuscated." In direct contrast to the perfect MIS XLIF (without instrumentation) fusion rate, I would offer the study by Berjano *et al.*, in which the authors assessed the fusion rates utilizing CT studies (more accurate than X-rays) 1 year following MIS XLIF utilizing different bone graft supplements to fill cages [Table 2].[5] Fusion was documented in a much lower number of patients (e.g. just 68 of 78 patients (87.1%)).

Non-neurological complications of minimally invasive surgery surgery (MIS) extreme lateral interbody fusion (XLIF) vs. other procedures

Multiple additional medical/surgical complications, excluding neurological deficits, were attributed to MIS XLIF [Tables 1 and 2].[7,8,12,19,20,30] Epstein observed the following major complications of MIS XLIF (e.g. likely vastly underreported due to our medicolegal system); sympathectomy, major vascular injuries (some life ending, others life-threatening), bowel perforations, seromas, malpositioning of MIS XLIF cages with extrusion or contralateral foraminal nerve root compression (e.g. cage-overhang).[12] In a study by Meredith *et al.*, 18 patients had thoracic MIS XLIF procedures at 32 levels; 22% (4 of 18) of the patients exhibited major surgical complications, and there were 5 medical complications.[19] The complication rate in a 2012 study by Caputo *et al.* involving 30 MIS XLIF/pedicle screw fixation (127 levels (average 4.2 levels) from T10-L5 with MIS ALIF (L5S1; 11 patients)) was 26.6%. This included a 11.8% pseudoarthrosis rate, with 6 (20%) other major (in part overlapping) complications; 2 (6.7%) of whom required further surgery; 1 lateral incisional hernia, 2 ruptures of the anterior longitudinal ligament (ALL), 2 wound breakdowns, 1 pedicle fracture, 1 nonunion, 1 cardiac instability.[7,8] For the 43 MIS XLIF performed in 21 patients in Oliveira *et al.* series, 2 (9.5%) patients required secondary surgery for stenosis.[20] In a study by Youssef *et al.*, complication rates for MIS XLIF peri and postoperatively were 2.4% and 6.1%, respectively.[30] Isaacs *et al.* examined radiographic outcomes of 107 MIS XLIF (average 4.4 levels/patient; average age of 68 years) for adult scoliosis (18.7% no instrumentation, 75.7% pedicle screws, 5.6% lateral fixation). Complications (1 or more) occurred in 9% of the patients undergoing MIS XLIF without instrumentation, whereas 20.7% had complications with open posterior instrumented procedures (e.g. including 3 deep wound infections). Certainly, the increased surgical/medical risks of so many multilevel MIS XLIF should prompt spine surgeons to ask why so many older patients are being subjected to such extensive multilevel MIS XLIF (e.g. 4.2 and 4.4 levels/patient in two studies) leading to such high complication rates with/without additional instrumentation.

Lack of safety, efficacy, and superiority (some say inferiority) of minimally invasive surgery (MIS) extreme lateral interbody fusion (XLIF) over other constructs

Multiple studies demonstrated a lack of safety or efficacy of MIS XLIF over other available fusion constructs (e.g. MIS, ALIF, TLIF, PLIF, and PLF) (e.g. particularly regarding perioperative neurological/other morbidity) [Table 2].[14,16,23] When Lee *et al.* analyzed complications (including 3 transient lumbosacral plexus palsies) for 74 mini-open lateral approaches for 1–4 level MIS ALIF, they advised that, prior to trialing MIS XLIF or MIS DLIF, the enhanced risk of the latter approaches which placed the lumbosacral plexus at risk, should be further investigated.[16] In 2016, Hartl *et al.* compared the safety and efficacy of adding intraoperative neural monitoring (IONM) to perform MIS lumbar XLIF (24 case series; 18 used IONM) vs. MIS ALIF (8 randomized controlled trials and 1 case study), and one combined MIS XLIF/ALIF study [Table 2].[14]

MIS XLIF had a two-fold greater neurologic complication rate (8.92%) vs. MIS ALIF (4.96 %). Sembrano *et al*., in 2016, compared outcomes for treating low-grade degenerative spondylolisthesis (DS) with stenosis (SS) over a two-year period utilizing MIS XLIF (29 patients) vs. MIS TLIF (26 patients) [Table 2].[23] Results for the two procedures were similar; average opeative time for MIS XLIF vs. MIS TLIF (171 vs. 186 minute), and identical 2-day length of stay (LOS). However, there was significant less blood loss for MIS XLIF vs. MIS TLIF. Critically, however, new iliopsoas weakness occurred in 31% of MIS XLIF vs. 0% of MIS TLIF procedures. The data in this latter study further highlight the significant neurological risks posed by MIS XLIF.

Lack of superiority and potential inferiority of minimally invasive surgery surgery (MIS) extreme lateral interbody fusion (XLIF) vs. other constructs

Multiple studies emphasized either the lack of superiority of MIS XLIF over other constructs or in some cases, MIS XLIF's lesser performance [Tables 1 and 2].[3,25,28] In a review by Barbagallo *et al*. (e.g. only 6 quality articles of 258) regarding the relative safety, efficacy, and outcomes of 1 or more level MIS LLIF with/without instrumentation vs. MIS PLIF/TLIF for degenerative lumbar disease, they concluded there was "insufficient evidence of the comparative effectiveness of MIS LLIF versus MIS PLIF/TLIF surgery."[3] When Talia *et al*. compared the strengths and weaknesses of different MIS surgical techniques, comparing XLIF with TLIF, and ALIF, they concluded there were no adequate long-term data confirming the benefit/efficacy/safety of any these approaches over another.[25] Furthermore, in a review of 23 articles (19 study cohorts, 720 patients) utilizing different MIS interbody fusion techniques (MIS ALIF, MIS XLIF, MIS P/TLIF), Uribe *et al*. discovered "significant gains in both weighted average lumbar lordosis and segmental lordosis. following MIS interbody fusion," but did not single out XLIF.[28] Again, XLIF did not uniquely offer benefits over spinal constructs.

CONCLUSION

MIS XLIF were originally devised to provide increased end plate availability for interbody spinal fusion to better facilitate arthrodesis rates while providing indirect neural decompression. Anticipated major advantages included avoiding major vessel/visceral injuries seen with MIS ALIF, trauma to the posterior elements, and reduced operative time, blood loss, LOS vs. MIS TLIF/PLIF and PLF. Nevertheless, these multiple studies failed to document the safety, efficacy, or superiority of the MIS XLIF vs. the multiple other surgical alternatives. In fact, they documented the increased neurological and surgical/medical complication rates for XLIF that were in some instances life-threatening, or even, life-ending.[9,10-12] Shouldn't we, therefore, conclude that the cons of MIS XLIF outweigh its pros, and move to strike it from our surgical armamentarium?

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Conflicts of interest

There are no conflicts of interest.

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