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Review Article

Perspective; high frequency of intraoperative errors due to extreme, oblique, and lateral lumbar interbody fusions (XLIF, OLIF, LLIF): Are they "safe"?

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ABSTRACT

Background: Extreme Lateral Lumbar Interbody Fusions (XLIF), Oblique Lateral Interbody Fusion (OLIF,) and Lateral Lumbar Interbody Fusion (LLIF) were largely developed to provide indirect lumbar decompressions for spinal stenosis, deformity, and/or instability.

Methods: Here, we have reviewed and updated the incidence of intraoperative errors attributed to XLIF, OLIF, and LLIF. Specifically, we focused on how often these procedures caused new neurological deficits, major vessel, visceral, and other injuries, including those warranting secondary surgery.

Results: Performing XLIF, OLIF, and LLIF can lead to significant intraoperative surgical errors that include varying rates of; new neurological injuries (i.e. iliopsoas motor deficits (4.3-19.7-33.6-40%), proximal hip/upper thigh sensory loss/dysesthesias (5.1% to 21.7% to 40%)), life-threatneing vascular injuries (i.e., XLIF (0% - 0.4%-1.8%), OLIF (3.2%), and LLIF (2%) involving the aorta, iliac artery, inferior vena cava, iliac vein, and segmental arteries), and bowel/viscarl injuries (0.03%-0.4%) leading to reoperations (i.e., XLIF (1.8%) vs. LLIF (3.8%) vs. XLIF/LLIF/OLIF 2.2%)).

Conclusion: Varying reports documented that XLIF, OLIF and LLIF caused up to a 40% incidence of new sensory/motor deficits, up to a 3.2% incidence of major vascular insults, a 0.4% frequency of visceral/bowel perforations, and a 3.8% need for reoperations. These high frequencies of intraoperative surgical errors attributed to XLIF, OLIF, and LLIF should prompt reconsideration of whether these procedures are "safe."

Keywords: Extreme Lateral Interbody Fusions (XLIF), Oblique Lateral Interbody Fusion (OLIF), Lateral Lumbar Interbody Fusions (LLLIF), Surgical Errors, Mistakes, Vascular, Bowel, Neural, Injuries, Intraoperative Mistakes, Lack of Safety/Efficacy

INTRODUCTION

Extreme Lateral Lumbar Interbody Fusions (XLIF), Oblique Lateral Interbody Fusion (OLIF,) and Lateral Lumbar Interbody Fusions (LLIF) provide indirect lumbar decompressions largely addressing spinal stenosis, instability, and/or deformity. However, they have previously been reported to cause varying frequencies of neural injuries (i.e., iliopsoas sensory/motor deficits up to 40%, proximal hip/upper thigh sensory loss up to 40%), up to a 3.2% frequency of major vascular injuries (i.e., aortic, iliac artery, inferior vena cava, iliac vein, segmental arteries), a 0.4%

incidence of bowel/visceral injuries, and a 3.8% requirement for reoperations [Table 1].[1-21] Here we have updated the frequencies of these major intraoperative XLIF, OLIF, and LLIF surgical errors with the intent of determining whether these procedures are "safe".

VARYING FREQUENCIES OF BOWEL INJURIES CAUSED BY XLIF

Cadaveric Study Showing Higher Risk of Colon Perforation for L23 and L34 XLIF

When Yilmaz *et al.* (2018) evaluated 4 cadavers, they documented that XLIF performed at the L23 and L34 levels put the retroperitoneal colon at greater risk for perforation; "The mean distance from the intervertebral disc space to the ascending or descending colon was 23.2 mm at the L23 level, 29.5 mm at the L34 level, and 40.3 mm at the l45 level" [Table 1].[21]

Frequencies of Bowel Injuries Caused by XLIF

Multiple studies showed the risks of bowel injuries occurring for XLIF ranged from 0% -0.03%-0.4%, while LLIF resulted in a 0% incidence of bowel perforations [Table 1].[3,6,7,9,10,12,18,20] Rodgers *et al.* (2011) found a 0% incidence of visceral injuires in 600 XLIF procedures (80.8% 1-level, 15% 2-level XLIF).[18] Balsano *et al.* (2015) reported a 70-year-old patient who sustained a bowel perforation following a 2-level (L34/L45) XLIF.[3] Epstein in 2016 documented 2 cases of bowel perforations, and a third case discovered through a professional communication; later, in the 2019 literature review, Epstein cited a 0.4% incidence of reported bowel perforations.[6,7,9] Fujibayashi *et al.* (2017) quoted a 0.03% incidence of bowel injuries for XLIF, while Farber *et al.* (2023) quoted a 0% incidence of visceral injuries attributed to 286 LLIF (average 1.3 level) based on a review of 10 studies.[10,12] Overall, Walker *et al.* (2019) noted that patients undergoing 1874 PP (Prepsoas) a vs. 4607 TP (Transpsoas) approaches to XLIF exhibited similar frequencies of bowel injuries.[20]

VARYING FREQUENCIES OF MAJOR VASCULAR INJURIES CAUSED BY XLIF, OLIF, AND LLIF

Varying frequencies of major vascular injuries/surgical errors have been reported during XLIF (0% up to 1.8%), OLIF (up to 3.2%), and LLIF (up to 2%) [Table 1].[2,4,5,10,16-18,20]

Need to Document Anterior Lumbar Vascular Anatomy Prior to XLIF, OLIF, and LLIF Surgery

In an effort to limit major vascular injuries occurring during XLIF, OLIF, and LLIF procedures, multliple authors recommended obtaining preoperative radiological studies to document the anatomy of the lumbar great vessels [Table 1].[1,2,4,5,10,16-18,20] Alkadhim *et al.* (2015) emphasized that; "Understanding the vascular anatomy of the lateral and anterior lumbar spine is paramount for successfully and safely executing the LLIF procedure" [Table 1].[1] In their 3 cadaver study (i.e., including 6 bilateral Minimally Invasive (MI) LLIF approaches,) the aorta averaged 2.1 cm to the left, and the inferior vena cava (IVC) 1.4 cm to the right of the center of the lumbar discs, while the additional 2 lumbar arteries per level were located on either side of each vertebra [Table 1].[1] Buric *et al.* (2016) similarly recommended; "Detailed preoperative planning, based on radiological examination of vascular structures, should be a mandatory step prior to this specific surgical approach".[4]

Four Case Studies of Major Vascular Injuries Due to XLIF

Four cases of great vessel injuries occurred during XLIF (i.e. 3 of which were at L45); 1 injury resulted in a mortality, 1 resulted in shock due to a retroperitoneal hematoma, and there were 2 common iliac vein injuries (in one case also involving a lumbar plexus injury) [Table 1].[2,4,16,17] In one case report, Assina *et al.* (2014) observed a major vessel injury that occurred during a L45 MI XLIF that resulted in the patient's death.[2] In a second case, Buric *et al.* (2016) had a patient who sustained a common iliac vein/retroperitoneal hematoma due to a L45 XLIF that required an immediate life-saving intraoperative direct vascular repair; notably, there had been no preoperative studies to document the "aberrant" high location of the vena cava bifurcation.[4] They attributed the vascular injury to; "...inadequate preoperative analysis of the radiological documentation...", and emphasized; "Detailed preoperative planning, based on radiological examination of vascular structures, should be a mandatory step prior to this specific surgical approach". In a third case from Perio-Garcia *et al.* (2016), following a transpsoas (TP) MI XLIF, the patient sustained a life-threatening retroperitoneal hematoma, and hemorrhagic shock.[17] In a fourth case, Mousafeiris *et al.* (2021) found a 72-year-old male sustained both major artery and lumbar plexus injuries during an XLIF; the patient required an acute aortic repair followed by a delayed T10-S1 instrumented fusion accompanied by wound debridement for an intervening infection.[16] Notably, these authors recommended; "Spine surgeons should be aware of catastrophic major neurovascular complications associated with this procedure and be prepared to address them".

Risks of Major Vessel Injuries for XLIF (0% - 0.4%-1.8%), OLIF (3.2%), and LLIF (2%)

Three series showed varying frequencies of intraoperative major vessel injuries occurring during XLIF (0-0.4%-1.8%), OLIF (3.2%), and LLIF (2%) [Table 1].[5,10,20] Walker *et al.* (2019) observed a 1.8% incidence of major vascular injuries occurring during Prepsoas (PP) Lateral Lumbar Interbody

Table 1: Summary of XLIF, OLIF, and LLIF.

Author [Reference] Journal Date	Type Study # Patients	Study Design	Results	Results	Outcomes
Rodgers[18] Spine 2011	**Intraop + Early Postop AE XLIF 600 Cases-741 Levels XLIF** 80.8% 1 Level 15% 2 Levels 4% 3 Levels 0.2% 4 Levels	Including L45 Level-99.2% Add Instrumented Fusion-83.2% PS -Most Unilateral HB Changes Pre v Postop 1.38-LOS Mean 1.21 days Periop AE-6 wk postop 6.2%-	**9 (1.5%) in Hospital-Surgery Related**-17 (2.8%) Hospital Medical AE **6 (1%) Out OutPt Surgery AE**	5 (0.8%) Outpt Medical-No Wound Inf- No vascular Inj-No Visceral Inj -4 (0.7%) Transient postop Neuro Deficits-	**11 (1.8%) Resulted in Added Procedures or Reop**-"Complications of MI XLIF compare favorably with those from other MI fusion procedures"
Assina[2] J Neurosurg Spine 2014	**Major Vascular Inj MI XLIF L45**	**Fatality** Following XLIF	50-year-old F Fatal Intraop Vessel Inj	XLIF Mortality	Fatal XLIF L45 Level Vascular Injury
Balsano[3] Eur Spine J 2015	**Bowel Perforation XLIF**	70-year-old -**L34/L45 Lateral TP XLIF**	Bowel Inj XLIF	L34/L45 XLIF	Bowel Perforation
Alkadhim[1] Eur Sp J 2015	**Surgical Vascular Anatomy-MI LLIF** Approach-3 Cadaver-6 Approaches R/L Radiology Analysis	Goal: Evaluate Vascular Structures at Risk-**Aorta 2.1 cm to Left of Center Lumbar Cisc**-VC Right Lumbar from 1.4 cm Center Discs Each V Body 2 Lumbar Arteries (R/L) under Symp	Trunk-run Superior V Body-All Across Avg Length 3.8 cm	"Understan-ding the vascular anatomy of the lateral and anterior lumbar spine is paramount for successfully and safely executing the LLIF procedure"	"It is imperative to identify anatomical variations in lumbar arteries and veins with careful assessment of the preoperative images"
Buric[4] Eur Spine J 2016	Direct Lesion - Repair Common Iliac Vein (CIV) During XLIF-**Repair Major Vascular Inj CIV XLIF L45 DS High VC Bifurcation**	Inadequate Preop Work-up Success in Repair No Postop Sequelae	Index Spine OR Not Done-Detailed Preop Plan-Radiology Vessels	"... inadequate preoperative analysis of the radiological documentation resulted in the lesion"	"Detailed preoperative planning, based on radiological examination of vascular structures, should be a mandatory step prior to this specific surgical approach".
Epstein[6] Surg Neurol Int 2016	**Non-Neurologic Major AE XLIF**	Major AE-Sympathetic 4% vs. 15% ALIF, 3 Major Vessel Inj: 1 Fatal, 1 Life Threat Retrop Hematoma 1 Iatrogenic PsA	2 Bowel Perforation+1 Direct Report-1 Lateral Extrusion Cage	45% Risk Cage Overhang-Seroma, Instrument Failures	**« … tip of the iceberg… many US-based spine surgeons' fail to publish such AE...**
Epstein[7] Surg Neurol Int 2016	**XLIF Cons v Pros- Indirect Decompression-Fusion**	Avoid Major Bowel/ Vascular Injury of ALIF-Avoid Muscle Trauma TLIF PLIF PLF	Pros XLIF-Less EBL-Less OR Time-Shorter LOS	Pros XLIF-Higher Fusion-Lower Infections	**Cons Increased Morbidity-Increased Mortality**
Peiró-García[17] Rev Exp Cir Ortop Traumatol, 2016	**1 Retrop Hematoma** Case XLIF Transpsoas Approach MI XLIF	Risk to Segmental Arteries and Great Vessels At Risk	Stand Alone XLIF Hemor-rhagic Shock	Symptom Tachy Hypot Anemia	**Describe Serious AE Due to XLIF Retrop Life-Threatening Hematoma**
Sembrano[19] Spine 2016	**2-Year Outcomes, 29 MI XLIF v 6 MI TLIF** Fusions	55 Pts 1-2 Level L1-L5-Similar OR Time/LOS, XLIF 171 min,. MI TLIF 186 ml-Sig. Less EBL 79%	**More Hip Flex Wk XLIF (31%) vs MI TLIF 0-1(3.4%) XLIF**	**Sensory Deficits, 3 (10.3%) XLIF, 2 (7.6%) MI TLIF**, -Deficits Resolved 1 year	Similar 53% Disability XLIF v 57% MI TLIF "... 2 year results ... reasonable

(Contd...)

Table 1: *(Continued).*

Author [Reference] Journal Date	Type Study # Patients	Study Design	Results	Results	Outcomes
	All LG DS-XLIF Indirect Decomp-TLIF Direct Decomp	XLIF vs 27% MI TLIF (< 100 cc)	**New Motor Deficit-**		MI approaches for the treatment of lumbar degenerative pathology
Fujibayashi[12] Spine 2017	**AE LLIF/XLIF** Japan Nationwide Survey 2998 Cases Over 2 Years	Questionnaires 71 Institutions (12.3%) LLIF 2998 Case-1995 XLIF-1003 OLIF-Response 86.1%	540 AE: 474 84.8% Evaluate-Overall **AE Rate 18% Most A-Sensory Nerve Inj 5.1-**	**Psoas Weak 4.3-Majority Spont Re-Major Vascular Inj 0.03%-Bowel Inj 0.03%-** SSI 0.7%-**Reop 2.2%**	"Higher Rates sensory nerve injury and psoas weakness reported for XLIF and higher rates peritoneal laceration and ureteral injury reported for OLIF"
Yilmaz[21] Cureus 2018	**Risk Colon Inj XLIF Anatomy** Study-Direct Access Disc Space -**Risk Inj Retrop Colon 4 Cadavers,**	K wires Placed L1/2 to L45 Levels Measured Distance Wires to ASC and DESC Colon-Mean Distance Wires to ASC- DESC	Colon 23.2 mm at L23-29.5 mm L34-40.3 mm L45-	L1/2 Above Colon-Study Anatomy Retrop Colon During XLIF	**Bowel Perforation Suggest Great Risk Colon Inj L23 and L34**
Fogel[11] J Spine Surg 2018	**Neuro AE 74 Pts 150 Levels** XLIF No Muscle Relaxants No MuR vs. 124 Pts 238 Level XLIF with Mu-Neuro AE limited/ eliminated when Avoid MR's with XLIF	TP Approach with XLIF L34/L45 Failure IONM Due to Use of Mu-Most Common Inj XLIF Thigh Dysesthesias Pai-Hip Flex Wk -L34 and L45 XLIF Performed +/- MuR vs. NMuR-	**NMur 8/74 with 10.8% and with MuR 36/125 28.8**-Thigh AE (Dys Pain at 1 Month	0% NMuR vs. 3 wk Postop MuR pts-All NMur Thigh AE resolved 3 mos posto-v 17/125 at 3 mos + 6/125 at 6 mos thigh AE Persist MR group	No LE Wk in Conclude: **Omit MR allowed Evoked and Free running EMG More Reliable/ accurate Predict Proximity Neuro structures-Thigh AE in NMuR pts** limited/ elim 3 mos
Epstein[9] Surg Neurol Int 2019 Risks	Risks/Comp, XLIF/MI-XLI-**AE XLIF, Injuries** lumbar plexus, ilioinguinal, iliohypogas-t-ric, genitofemoral, lateral femoral cutaneous, subcostals,	**AE XLIF, Continue**-sympathectomy, major vessel injury, Bowel perforation, Postop ileus, seroma, pseudarthrosis, subsidence, reoperations	**Limit vascular Injuries** ALI-**Limit Trauma to Tissues** TLIF/ PLIF, PLF-**AE Incidence** Neural Injury 30-40%,	**AE Incidence** Lumbar Plexus 13.28%, Sensory 21.7-40%, Motor 33.6-40%, Iliopsoas weakness 9-31%-	Anterior thigh/ groin pain 12.5-34%Sympathect-omy 4-12%-Non Neurologic AE-Major vascular injuries 0.4-Bowel perforations 0.4% Cage Overhang 45% Pseud 7.5%
Epstein[8] Surg Neurol Int 2019	ION-Limit Injury During XLIF/MI XLI-Unsafe? **XLIF/MI XLI-Significant Risk Neural injury with XLIF**	-Use IONM to Limit Root Injuries ION-Finger Electrode-MEP-No Muscle Relaxants (NMR-t-EMG	**Finger Electrodes Reduced 38% (7of 18 cases) to 14% with IONM 5 of 26 cases-**	MEP Reduced Deficits 2 series: RecommendedRoutine Adoption MEP-	Recommended NMR Better Continuous EM-T-EMG: Reduced Postop Neuropraxia Limit Retraction Time
Li[14] World Neurosurg 2019	Safety OLIF v XLIF-Initial Stage Learning Curve XLIF Avg Age 58.4 yrs old-OLIF Avg 56.1 yrs old-	No Sig Difference: Age Sex OR time, EBL, Levels, F/O AE 10% XLIF Sig Lower vs. OLIF 33.3%	**OLIF Higher Risk Neural Vascular Inj Initial Learning Curve**	"By contrast the XLIF approach is simple and the incidence of complications is relatively low"	XLIF more accepted Initial Stages of Anterolateral Lumbar Interbody Fusion

(Contd...)

Table 1: *(Continued).*

Author [Reference] Journal Date	Type Study # Patients	Study Design	Results	Results	Outcomes
Walker[20] J Neurosurg Spine 2019	AE MI Lateral Interbody fusions MA PP v TP Approach	Analysis AE 1874 pts PP v 4607 TP-TP Higher Rate Transient Sensory 21.7% Deficits v. PPs rate 8.7%	TP Hip Flexor Wk Transient 19.7% vs. PP 5.7%-Permanent Motor Deficit TP 2.8% vs. PP 1.0%	Symp N Inj PP 5.4% vs. 0% T-Non Neuro AE **Major Vascular Injury Higher PP 1.8% vs. 0.4% TP**	Same % GU and Bowel Injury, Ileus, hematoma-Higher Infection TP 3.1% vs. 1.1% PP
Mousafeiris[16] Cureus 2021	Both Major Artery and Lumbar Plexus Inj Primary XLIF	Vascular/ neurovascular AE XLIF 72-year-old -Outside XLIF Postop Neuropathic Pain, Incomplete Paraplegia BLE/Infection	AE Aortic +Lumbar Plexus In-Reop-T10=S1 PLF Inf Removal Fusion +Debride	**".. the report of major vascular injuries, although rare, has questioned its safety profile"**	"Spine Surgeons should be aware of catastrophic major neurovascular complications associated with this procedure and be prepared to address them?
Emami[5] N Am Spine Soc J 2023	Compare 408 OLIF v 602 XLIF MI Spinal Fusions-Instability XLIF to access L5S1	One Level L1-L5-24 Studies-Rate Neuropraxia Sig. Greater XLIF 21.2% vs. 10.9% OLIF	**Vascular Inj Higher OLIF 3.2% v 0.0 XLI**-Similar Outcomes ODI VAS 2 groups	"similar clinical and radiological outcomes"-**XLIF Higher Neuro-praxia**-OLIF More Vascular Inj	„...patient specific anatomical factors such as vascular anatomy or iliac crest height greatly influence which technique to use
Mima[15] J Orthop Sci 2023	Hidden EBL XLIF, 30 ASD Pts Avg Age 68.7 F/O Avg 2 yrs	Multilevel XLIF Avg 2.5 Levels PSF 3-5 d later EBL XLIF Underestimated-**Hidden EBL (HBL)=Total EBL-Intraop EBL**	Postop HB Sig. Decrease-11.8 to 10.-HCT Decrease 36 -32 ml	HBL was 258 cc+/- 168 ml-Gross Eq **HBL in XLIF was 8 X Greater vs. IBL**	"During the perioperative course... XLIF, surgeons need to pay attention not to underestimate the TBL".
Farber[10] J Neurosurg Spine 2023	Prone **LLIF** Single Position Surgery with PS Pron-10 Studies-286 Patients Prone LLIF Mean 1.3 Levels	**18 Pts Intraop AE**: Cage Subsidence 3.8%; ALL Rupture 2.3%; Cage Reposition 2.1%; **Segmental Artery Inj 2% (5/244 Pts)**	(5/2444); Aborted prone Interbody Placement (2/244); Durotomy 0.6%	**No Major Vascular Inj -N0 Peritoneal In**-68 Postop AE: Hip Flexor Wk 17.8%-Thigh/Groin Sensory 13.3%	**Revision Surgery 3.8%**-Wound Inf 1.9%; Psoas Clot 1.3%;-Motor Neural Injury 1.2%-Single Position LLIF Prone: **"...appears to be a safe surgical approach with a low complication profile. "**

Comp=Complications, XLIF=Extreme Lateral Interbody Fusion, AE=Adverse Events, MI=Minimally Invasive, TLIF=Transforaminal lumbar Interbody Fusion, PLIF=Posterior Lumbar Interbody Fusion, ALIF=Anterior lumbar Interbody Fusions, PLF=Posterior Lumbar Fusion, IONM=Intraoperative Neural Monitoring t-EMG=Triggered EMG, Postop=Postoperative, v=Versus, OR=Operating Room, LOS=Length of Stay, DS=Degenerative Spondylolisthesis. LG=Low Grade, Pts=Patients, Sig=Significantly, Flex=Flexion, Wk=Weakness, Decomp=Decompression, EBL=Estimated Blood Loss, ASD=Adult Spinal Deformity, PSF=Posterior Spinal Fusion IBL=Intraoperative Blood loss, HBL=Hidden Blood Loss Eq=Equation, AE=Adverse Events, Retrop=Retroperitoneal, PsA=Pseudoaneurysm, Sympathect=Sympathectomy, Inj=Injury, Threat=Threatening, Tachy=Tachycardia, Hypot=Hypotensive LLIF=Lateral Lumbar Interbody Fusion, OLIF=Oblique Lumbar Interbody Fusion, F/O=Follow-up, MA=Meta=analysis, PP=Prepsoas, TP=Tanspsoas, Symp=Sympathetic, GU=Urological, CIV=Common Iliac Vein, ASC=Ascending, DESC=Descending, MuR=Muscle Relaxants, NMuR=No Muscle Relaxants, Dys=Dysesthetic VAS=Visual Analog , R=Right, L=Left Scale, ODI=Oswestry Disability index, BLE=Bilateral Lower Extremities, Inf=Infection, V=Vertebral Body, VC=Vena Cava, PS=Pedicle Screw Fixation, Spont=Spontaneous, Res=Resolution OutPt=Out Patient, Tech=Techniques, yrs=Years, d=days, wk=Week, mos=Months, Pseud=Pseudarthrosis

Fusions (LLIF in 1874 patients) vs. a lower 0.4% incidence for Transpsoas (TP) Lateral Lumbar Interbody Fusions (LLIF in 4607 patients).[20] Rodgers *et al.* (2011) found a 0% incidence of vascular injuries during 600 XLIF procedures.[18] Emami *et al.* subsequently (2023) documented that although adverse vascular events occurred in 3.2% of 408 1-level OLIF,

the rate was again 0% for 602 1-level XLIF.[5] Notably, of the 286 patients undergoing average 1.3 level LLIF in Farber *et al*. (2023) study, 5 (2%) intraoperative vascular errors (i.e. occurring in 5/244 patients) were attributed to segmental artery injuries [Table 1].[10]

VARYING FREQUENCIES OF NEURAL INJURIES/ERRORS CAUSED BY XLIF, OLIF, LLIF

Development of Intraoperative Neural Monitoring Protocols to Limit XLIF Neural Errors

In 2019, Epstein cited varying frequencies of neural injuries largely attributed to XLIF; lumbar plexus injuries (13.28%), new sensory deficits (21.7%- 40%), new motor loss (33.6%-40%), and iliopsoas weakness (9%-31%) [Table 1].[9] These deficits prompted the development of multiple intraoperative neural monitoring protocols that were increasingly applied to XLIF to limit such neurological deficits. These modalities very importantly included finger electrodes (i.e., without IONM neural injuries occurred in 38% (7 of 18 cases) of patients, but were reduced to 14% (50 of 26 cases) of patients undergoing surgery utilizing IONM).

Eliminating Intraoperative Muscle Relaxants to Limit XLIF-Related Neural Injuries

Fogel *et al*. (2018) found that eliminating muscle relaxants during XLIF (NMuR) reduced the incidence of new motor neurological deficits to 10.8% (i.e. in 8 of 74 cases for L34/L45 XLIF) vs. a higher 28.8% (i.e. in 36 of 125 cases for L34/L45 XLIF) seen when using muscle relaxants (MuR).[11] This makes sense as muscle relaxants largely eliminate the ability to monitor/perform electromyography or motor evoked potentials.

Incidences of Neural Injuries with Prepsoas (PP) vs. Transpsoas (TP) Minimially Invasive (MI) XLIF

When Walker *et al*. (2019) evaluated the incidence of neurological deficits caused by Prepsoas (PP: 1874 patients) v Transpsoas (TP: 4607 patients) MI XLIF approaches, they found TP procedures caused more transient sensory deficits (21.7%) vs. PP (8.7%) procedures. Further, MI XLIF also resulted in more motor deficits using Transpsoas v. Prepsoas procedures; specifically, TP caused greater hip flexor weakness (19.7%) vs. PP (5.7%), and TP caused more other permanent motor deficits (2.8%) vs. PP (1.0%) procedures.[20]

High Rates of Intraopereative Neurological Injuries/ Surgical Errors Attributed to XLIF, OLIF, and LLIF

High rates of intraoperative neurological injuries/surgical errors were caused by XLIF, OLIF, and LLIF; frequencies of new proximal motor/sensory neural deficits due to XLIF approached 40%, with a reported 10.9% incidence of neuropraxia attributed to OLIF; also multiple new neurological deficits occurred secondary to LLIF (i.e., hip flexor weakness (17.8%), thigh/groin sensory loss (13.3%), and motor neural injuries (1.2%)) [Table 1].[5,9,10,11,18-20] Rodgers *et al*. (2011) found 4 (0.7%) transient postoperative neurological deficits following 600 XLIF procedures.[18] In Sembrano *et al*. (2016), they documented a higher rate of hip flexor weakness caused by MI XLIF (31% of 29 cases) vs. MI Transforaminal Lumbar Interbody Fusions (MI TLIF; 0% of 26 cases); they also reported 1 (3.4%) new motor deficit for a MI XLIF and 3 (10.3%) new sensory deficits for MI XLIF vs. 2 (7.6%) for MI TLIF (i.e., all TLIF deficits resolved within 12 months).[19] For the 24 studies evaluated in Emami *et al*. (2023) involving 408 OLIF (1-level) vs. 602 XLIF (1-level), they found a higher 21.2% incidence of neuropraxia for XLIF (21.2%) vs. a lesser 10.9% for OLIF.[5] In Farber *et al*. (2023) summary of 10 studies involving 286 patients undergoing average 1.3 level LLIF, they encountered a high frequency of new hip flexor weakness (17.8%), thigh/groin sensory loss (13.3%), and motor neural injury (1.2%).[10]

FREQUENCY OF HIDDEN/INACCURATE ESTIMATED BLOOD (EBL) AND TOTAL BLOOD LOSS (TBL) REPORTED FOR XLIF

Mima *et al*. (2023) looked at 30 patients undergoing average 2.5 level XLIF, followed by lumbar pedicle/screw fusions performed between 3-5 days later; the pathology being addressed was adjacent segment disease (ASD) [Table 1].[15] The hemoglobin levels decreased from 11.8 g/dl preoperatively to 10 g/dl postoperatively, while the hematocrits diminished from 36% to 32%. They concluded that HBL (hidden blood loss) for XLIF was 8-fold greater than the estimated intraoperative blood loss (EBL), and warned surgeons; "During the perioperative course, XLIF surgeons need to pay attention not to underestimate the TBL".[15]

REOPERATION RATES FOR PATIENTS UNDERGOING XLIF (1.8%) VS. LLIF (3.8%)

The frequencies of reoperations attributed to surgical errors in the larger series, but also including data from the 5 case studies, were variably reported for XLIF (up to 1.8%), LLIF (up to 3.8%), and XLIF/LLIF/OLIF combined (up to 2.2%) [Table 1].[2-4,10,12,16-18] The 5 case studies involved 4 acute great vessel injuries occurring during XLIF/MI XLIF warranting immediate intraoperative repairs, plus one additional report of an acute bowel perforation.[2-4,16,17] In 2011, Rodgers *et al*. found that 11 (1.8%) of 600 patients undergoing XLIF required additional surgery.[18] When Fujibayashi *et al*. (2017)

performed a combined evaluation of LLIF (2998 patients) vs. XLIF (1995 patient) vs. OLIF (1003 patients), the overall reoperation rate was 2.2%.[12] In Farber *et al*. (2023) evaluation of 10 studies including 286 patients undergoing average 1.3 level LLIF, the reoperation rate was an even higher 3.8%.[10]

ARE XLIF, LLIF AND OLIF "SAFE" DESPITE HIGH INTRAOPERATIVE SURGICAL ERROR RATES?

Despite high frequencies of surgery-related intraoperative errors, authors in several series concluded that XLIF/LLIF/OLIF were "safe" [Table 1].[10,14,18,19] Discussing the initial stages of the learning curve, Li *et al*. (2019) found more surgical errors occurred with OLIF (33.3%) (i.e., especially neural, and vascular mistakes) vs. XLIF. (10%).[14] However, they concluded; "By contrast the XLIF approach is simple, and the incidence of complications is relatively low"; this conclusion seemed to ignore the still unacceptably high 10% XLIF error rate. Although Rodgers *et al*. (2011) discussed multiple surgical errors occurring with 600 XLIF (i.e., 9 (1.5%) in hospital surgery-related complications, and 6 (1%) outpatient surgical complications within 6 postoperative weeks), they did not question the "safety of MI XLIF". 18] Rather they stated; "Complications of MI XLIF compare favorably with those from other MI fusion procedures".[18] Despite Sembrano *et al.* (2016) observing the high incidence of intraoperative errors attributed to MI XLIF (29 patients) vs. MI TLIF (26 patients) (i.e., 31% hip flexor weakness MI XLIF vs. 0% with TLIF, 3.4% new motor deficits with MI XLIF vs. 0% TLIF, 10.3% sensory deficits MI XLIF vs. 7.6% MI TLIF)), they nevertheless concluded that MI XLIF were; "... reasonable minimally invasive approaches for the treatment of lumbar degenerative pathology".[19] Although Farber *et al*. (2023) summarized high intraoperative error rates for 286 LLIF from 10 studies (i.e., 2.3% cage repositioning; 2% segmental artery injury (5/244 patients); aborted interbody device placements (2/244); hip flexor weakness 17.8%; and 3.8% operative revision rate), they too somehow concluded that LLIF; "... appears to be a safe surgical approach with a low complication profile."[10] However, the data available to these multiple authors should have led to the more logical conclusion that XLIF/MI XLIF were NOT "safe".[10,14,18,19]

MULTIPLE AUTHORS CONSIDER XLIF/OLIF NOT TO BE "SAFE" DUE TO HIGH ERROR RATES

Multipel authors were concerned about the "safety" of XLIF/MI XLIF/OLIF procedures due to their high intraoperative surgical error rates.[2-9,12,16,17,20,21] On several occasions, Epstein (2016, 2019), noted the high intraoperative surgical morbidity/error rates, and mortality of XLIF.[6,7,9] The 5 authors of XLIF/MI XLIF case studies involving 4 acute great vessel injuries (i.e. including one death and 3 lift-saving laparotomies), and one acute bowel perforation, were clearly concerned about the "safety" of these procedures.[2-4,16,17] Specifically, in Mousafeieis *et al*. (2021) XLIF case, a 72-year-old sustained both major vascular and lumbar plexus injuries, prompting the authors to emphasize their "safety" concerns; "Spine surgeons should be aware of catastrophic major neurovascular complications associated with this procedure and be prepared to address them".[16] Fujibayashi *et al*. (2017) also questioned the safety of XLIF and OLIF noting; "...higher rates of sensory nerve injury and psoas weakness for XLIF, and higher rates of peritoneal laceration and ureteral injury for OLIF".[12] Emami *et al*. (2023) also observed the high risk of surgical errors attributed to both OLIF vs XLIF procedures, and found; "...similar clinical and radiological outcomes..." for the two procedures with XLIF resulting in more neuropraxic injuries, and OLIF producing more vascular perforations.[5] Walker *et al.* (2019) discussed the higher rates of sensory and motor deficits attributed to Transpsoas (TP: 4607 patients) Lateral Lumbar Interbody Fusions (LLIF) vs. Prepsoas LLIF (PP: 1874 patients); sensory deficits occurred in 21.7% of TP LLIF vs. 8.7% for PP XLIF, and there were also more motor deficits (i.e. TP LLIF hip flexor weakness 19.7% vs. PP LLIF 5.7%).[20] However, PP LLIF caused more major vascular injuries (1.8%) vs. TP LLIF (0.4%). Their "safety" concerns were couched in the following terms; "These results can facilitate informed decision-making and tailored surgical planning regarding the choice of minimally invasive anterolateral access to the spine."[20]

CONCLUSION

XLIF, OLIF, and LLIF collectively cause up to a 40% incidence of new sensory and motor deficits, up to a 3.2% incidence of major vascular insults, a 0.4% incidence of reported visceral/bowel perforations, and a 3.8% need for repeat surgery. With such high frequencies of intraoperative surgical errors the spine surgical community should be now concluding that these XLIF, OLIF, and LLIF approaches are not "safe".

Declaration of patient consent

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