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Review Article

Perspective: How can risks to patients be limited during spine surgeons' learning curves?

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ABSTRACT

Background: Learning curves (LC) are typically defined by the number of different spinal procedures surgeons must perform before becoming "proficient," as demonstrated by reductions in operative times, estimated blood loss (EBL), length of hospital stay (LOS), adverse events (AE), fewer conversions to open procedures, along with improved outcomes. Reviewing 12 studies revealed LC varied widely from 10-44 cases for open vs. minimally invasive (MI) lumbar diskectomy, laminectomy, transforaminal lumbar interbody fusion (TLIF), anterior lumbar interbody fusion (ALIF), and oblique/extreme lateral interbody fusions (OLIF/XLIF). We asked whether the risks of harm occurring during these LC could be limited if surgeons routinely utilized in-person/intraoperative mentoring (i.e., via industry, academia, or well-trained colleagues).

Methods: We evaluated LC for multiple lumbar operations in 12 studies.

Results: These studies revealed no LC for open vs. MI lumbar diskectomy. LC required 29 cases for MI laminectomy, 10-44 cases for MI TLIF, 24-30 cases for MI OLIF, and 30 cases for XLIF. Additionally, the LC for MI ALIF was 30 cases; one study showed that 32% of major vascular injuries occurred in the first 25 vs. 0% for the next 25 cases. Shouldn't the risks of harm to patients occurring during these LC be limited if surgeons routinely utilized in-person/intraoperative mentoring?

Conclusions: Twelve studies showed that the LC for at different MI lumbar spine operations varied markedly (i.e., 10-44 cases). Wouldn't and shouldn't spine surgeons avail themselves of routine in-person/intraoperative mentoring to limit patients' risks of injury during their respective LC for these varied spine procedures ?

Keywords: Learning Curve, Risks, Adverse Events, Neurological Deficits, Pros, Cons, Morbidity, Minimally Invasive (MI), Transforaminal Lumbar Interbody Fusions (TLIF), Anterior Lumbar Interbody Fusion (ALIF), Oblique/Extreme Lateral Interbody Fusions (OLIF/XLIF), Other Operations, Outcomes, Definition Learning Curve, Need for Mentoring

INTRODUCTION

For spinal surgeons, learning curves (LC) are defined by the number of spine procedures surgeons must perform before becoming "proficient" as demonstrated by reductions in operative times, estimated blood loss (EBL), length of hospital stays (LOS), adverse events (AE), fewer conversions to open procedures, and with improved outcomes. During neurosurgery or orthopedic residency training programs, the risks to patients during residents' learning curves (LC) are limited by the attending surgeons' "direct supervision". However, how are these risks mitigated during the varied LC documented for new/different spine procedures introduced after residency (i.e., minimally invasive (MI) diskectomy, laminectomy, transforaminal lumbar interbody fusion (TLIF), anterior lumbar interbody fusion (ALIF), and oblique/extreme lateral interbody fusion (OLIF/XLIF), cervical fusions) [Table 1]?[1-12] Specifically, we asked whether the risk of harm occurring during the varied LC (i.e., 10-44 cases) could be limited if spinal surgeons availed themselves of in-person/intraoperative mentoring opportunities provided by industry, academia, and/or well-trained colleagues.

Defining Learning Curves for Minimally Invasive (MI) Spine Operations

Minimally invasive (MI) spine operations were largely devised to reduce operative time, tissue trauma, and perioperative morbidity [Table 1].[1-12] Learning curves (LC) for performing the different MI procedures are typically defined by marked reductions in operative times, estimated blood loss (EBL), length of stay (LOS), frequency of adverse events (AE), and fewer conversions to open procedures, with improved outcomes (i.e., better Visual Analog Outcomes Scores (VAS)) [Table 1].[1-12] Specifically, Ferry (2021) added that spine surgeons' education/expertise should allow them to meet the LC criteria by demonstrating a reduction of operative time, postoperative recovery times, and better results [Table 1].[3] They further observed that just 59.3% of 12 studies summarized surgeon experience, 41.7% discussed total years of surgeon practice, and just 16.7% of surgeons had performed traditional open procedures, were fellowship trained, and had cadaver course/lab training prior to performing MI operations.

No Learning Curve for Microdiskectomy

Several studies documented no LC cases were required for conversion from open to performing MI microdiscectomy [Table 1].[2,12] Epstein's (2017) review of the literature showed there was no learning curve required to achieve "proficiency" for performing MI diskectomies.[2] Vaishnav *et al*. (2022) also confirmed the absence of a LC for completing 114 microdiskectomies.[12]

Learning Curve for MI Transforaminal Lumbar Interbody Fusion (TLIF)

Six studies focused on the wide variation in LC reported for MI TLIF [Table 1].[1,2,5,9,10,12] Reviewing 14 articles involving 966 operations, Sclafani and Kim (2014) defined the overall LC as; "... the change in frequency of complications and length of surgical time as case number increased" for 5 spine operations.[10] These 5 procedures included; MI lumbar decompression, MI TLIF, MI percutaneous pedicle screw insertion, laparoscopic anterior lumbar interbody fusion (ALIF), and MI cervical surgery; the learning curves for these procedures ranged from 20-30 cases [Table 1].[10] Lee *et al*. (2014) discussed the first 44 MI TLIF as LC cases (vs. the latter 46 cases) as required before one surgeon (2004-2009) demonstrated "proficiency" (i.e., defined by reduced average operative times, duration of fluoroscopy, and better outcome) [Table 1].[5] Interestingly, both of Lee's patient groups sustained comparable AE; the first 44 patients had 1 dural tear and 2 asymptomatic cage migrations vs. the latter 46 patients who experienced 1 asymptomatic cage migration. Additionally, fusion rates were similar for both groups, and no patient from either group required conversion to an open procedure. For 65 consecutive patients undergoing 1-level MI TLIF followed for at least 1 postoperative year (2008-2011), Nandyala *et al*. (2014) observed that the first 33 cases (Group A) were required to satisfy the LC (i.e., vs. the latter 32 cases (Group B)). [Table 1].[9] Group A patients required; longer average operating room times, more EBL, more intravenous fluids, longer anesthesia times, 1 had a CT-documented medial pedicle wall breach, 2 pseudarthroses occurred, 1 demonstrated graft migration, while 2 patients required revision procedures. Group B patients had fewer AE; 2 exhibited pseudarthrosis, one had an infection, while 3 patients required additional surgery. Notably, patients from each group sustained 2 dural tears, 2 instances of "neuroforaminal bone growth," and comparable LOS. In 2017, Epstein defined the LC for MI TLIF as ranging from 10-44 cases, while LC for other procedures warranted 20-30 cases (i.e., including MI diskectomy, MI cervical procedures, MI ALIF, and thoracolumbar pedicle screw techniques).[2] Ahn *et al*. (2022) further determined in 9 articles, including 753 patients, that the LC for MI TLIF required 31.33 +/- 11.98 cases (range 13-45 cases) [Table 1].[1] Vaishnav *et al*. (2022) found the LC for MI TLIF required 31 cases [Table 1].[12]

LC for MI Oblique Lumbar Interbody Fusion (OLIF) and Extreme Lateral Interbody Fusion (XLIF)

Two studies showed the LC for OLIF was achieved after 24-30 cases vs. 30 cases required to satisfy the LC for XLIF [Table 1].[6,7] In 2019, Liu *et al*. determined the LC for MI OLIF occurred after the first 24 (Group A) vs. the latter 25 cases (Group B); Group A patients still required more operating room time, longer X-ray exposure times, and demonstrated a much higher 37.5% rate of AE rate (i.e., thigh numbness, motor deficits, neural injuries, and ileus) vs. 20% for group B patients [Table 1].[7] Nevertheless, both groups exhibited similar clinical and radiological outcomes. The LC in Li *et al*. (2019) patients undergoing OLIF or XLIF occurred after the first 30 cases. [Table 1].[6] Interestingly, a 10% rate of AE was seen for XLIF vs. a much higher 33.3% AE rate for OLIF, with the latter demonstrating more neurological and vascular injuries during the LC. Nevertheless, patients' average ages were similar for

Table 1: Initial Learning Curves (LC) for Different Types of Spine Surgery.

Author [References] Date	Study Design	Results	Results	Results	Outcomes
Lee[5] J Spinal Disord Tech 2014	90 MIS TLIF LC 2004-2009 1 Surgeon 44 Early 46 Late Groups	LC Early 44 Cases >Avg OR Time, >Avg Fluoro Time, > Pain Postop	LC MIS TLIF 46th Better 3 Factors < Avg Or time < Fluoro time > Pain Rx	2nd Group Better VAS, ODI, NASS Scores Same Fusion Rates No Open OR	AE Early Gp: 1 DT, 2 ASx Cage Migration AE Later Gp 1 ASx Cage Migration
Nandyala[9] Spine J 2014	LC for MIS TLIF 65 Cases Min 1 yr F/O-EMR + Intraop/ Postop CT Pedicle Screws	Retro1 Center 2008-2011 Unilateral 1 Level DDD or LSS with Grade I/II Olisthy	Compared 1st Cohort 33 LC Concluded vs. 2nd Cohort 32 -Studied Intraop/Postop AE/Comp CT Findings	1st Cohort Sig Longer Avg OR Time, > Avg EBL, > Avg IV Fluids, >Time Anes, 1 Pedicle Wall Violation	Similar AE Both 2 DT 2 Foraminal Bone Overgrowth Similar LOS
Sclafani[10] Clin Orthop Relat Res 2014	SDec/Fus Comp/ AE LC-15 Studies (14 Used) 966 MI OR	LC Defined Change Comp and OR Time with More Cases	5 MIS Surg LDec, MITLIF PPSI, LALIF MICerv	Comp SDec: Most DT Comp Fusion Implant Malposition Nerve Injury Nonunion	Postop Comp 11%= 109/966 LC Case # 20-30 Difficulty Comparing Studies Due to: Early Cases Better Selected No Standard Varied Study Design
Epstein[2] SNI 2017	Aim MIS Spine Surg Define LC By Reduce OR Time Dissection Morbidity	LC 0 for Open vs. MI Disc LC for TLIF 10-32 40 -44 Cases	Other LC Proficiency 20-30 Cases Included 5 OR MI Disc MI TLIF MIS Cervical, MI ALIF, Pedicle screws Lum/Th	Concluded Need Better Mentoring Programs to Limit Morbidity/AE	Very Limited Literature Focused on LC for Spinal Surgery LC Ranged from 0-10-44 For Different Procedures
Sharif[11] World Neurosurg 2018	Measure AE for LC OR Time # Covert Open Surgery VAS LOS Outcomes	MI OR <Known Anatomy <Tactile Feedback <<Work Area Unfamiliar Endo	Need Right Instruments OR Team Radiographers	"Structured training with cadavers and lots of practice, preferably while working under the guidance of experienced surgeons, is helpful".	LC overall 30th Case but Lack of Specific OR
Liu[7] World Neurosurg 2019	MIS Surgery OLIF for LDD LC One Surgeon Initial Phase	1st 24 Pts (Gp A) 2nd 25 pts (Gp B)	Gp A Sig > OR Time + More X-ray Exposure	AE/COMP Gp A 37.5% Gp B 20% 8 Thigh Numb 3 Iliopsoas Quad Weakness 2 SympNI 1 Ileus	Same Clinical + Radiological Outcomes Sig LC OLIF OR Time/X-ray Exposure, Comp
Li[6] World Neurosurg 2019	OLIF and XLIF Initial LC LDD First 30 Cases	Similar Avg Ages XLIF 58.4 yrs Vs. OLIF 56.1 yrs	Comparable Clinical Data Age, Sex, OR Time, EBL, Levels, F/O OLIF > Risks Neurovascular AE Initial LC	Comp/AE XLIF 10% Sig Lower vs. OLIF 33.3%	"XLIF is more acceptable in the initial stage of anterolateral lumbar interbody fusion."

(Contd...)

Table 1: *(Continued).*

Author [References] Date	Study Design	Results	Results	Results	Outcomes
Kimchi[4] Global Spine J 2020	LC One Surgeon Retro Eval SS Th/Lum 2012-15	MI SS vs. Open SS 230 Pts >Lumbar Disk MI Group	More Tumor Surgery for Open SS	Over 4 Postop yrs: > Complex + < AE Due to Careful Pt Selection	Challenge Create Education for MIS Surgeons to Reduce LC
Ferry[3] Clin Spine Surg 2021	LC for Instru MIS SS- Present Evidence Training Experience 12 Studies	Assess LC Instru MIS SS Used PUB-Med Medline Prisma Guide	Surgeon Experience Training Purpose MI Instru Fus: < OR Time, >Recovery >Outcomes Just 7 Studies 59.3% Looked at Experience:	41.7% Eval yrs in Practice 16.7% Open Traditional OR 16.7% Resident Fellowship 16.7% Use Cadaver Course or Lab Training	8.3%Design OR Team 0 Eval Surgeon Experience SS LC Series MI Instru Fus Failed Look at Surgeon Experience
Mirza[8] J Am Acad Orthop Surg Glob Res Rev 2022	LC for MIS ALIF + Posterior Percut Fusion Vascular + Ortho Team L45/ L5S1	2010-2018 120 Pts Same OR Time <<EBL After Case 30 (LC 30)	Mean EBL 184 cc L5S1 232 cc L45 458 cc 2 L4-S1 20 Vascular AE/Injuries Required Primary Repair/Pack	Vascular AE Decreased Over Time 1st 25 Cases: 32% Vascular Injuries vs. 2nd 25 Cases 0%-Highest Postop Comp 1st 25 Cases	BMI > 35 >Vascular AE >OR Time, > AE LC 25-30 for MIS ALIF with PPF
Ahn[1] Eur Spine J 2022	LC for MIS TLIF Number Cases for LC-Used Databases PubMed Embase Cochrane Library	9 Articles 753 Pts Studied OR Time, Comp/ AE Rate	LC for OR Time 31.33 +/- 11.98 Cases (Range 13-45) Plateau LC for MIS TLIF Depends on AE/ Comp Measures	"The learning rate may be affected by the patients' and technical conditions."	"... great care is required in interpreting the learning curve and cutoff point for MI-TLIF proficiency."
Vaishnav[12] Clin Spine Surg 2022	Eval LC ION MIS ALIF/ PPS L45/L5S1 OR Time Radiation Exposure	1 Level 114 Microdisc 79 Lam 77 MIS ALIF	LC OR Setup ION/ Imaging No LC for Microdisk 23/79 Lam 31/77 MI ALIF Increased OR Time ION 0 Microdisc 36 Lam 31 MI ALIF	Fluoro Time No LC Radiation Dose 42 Microdisc 33 Lam NO LC for MI ALIF Unable Eval AE for Microdisc and MI ALIF	AE/LC of 29 Cases for Lam ION No Wrong Level Operations Varied by Surgery Type Most LC 25-35 Cases

MIS/MI=Minimally Invasive (Surgical), SDec=Spinal Decompression, Comp=Complications, AE=Adverse Events, LC=Learning Curve, OR=Operating Room, LDec=Lumbar Decompression, TLIF=Transforaminal lumbar interbody Fusion, PPSI=Percutaneous Pedicle Screw Insertion, LALIF=Laparoscopic Anterior Lumbar Interbody Fusion , MICerv=Minimally Invasive Cervical Surgery, Surg=Surgeries, DT=Dural Tear/Durotomy, Postop=Postoperative, CC=Consecutive Cases, Diff=Different, Min=Minimum, year/yr/yrs=Year(s) F/O=Follow-up, DDD=Degenerative Disc Disease, LSS=Lumbar Spinal Stenosis, Grade I/II Slip=Grade I/II Spondylolisthesis, EMR=Electronic Medical Record, CT=Computed Tomography, Intraop=Intraoperative, Eval=Evaluation, Sig=Significantly, Avg=Average, EBL=Estimated Blood Loss, IV=Intravenous, Anes=Anesthesia, LOS=Length of Stay, Postop=Postoperative, ALIF=Anterior Lumbar Interbody Fusion, SS=Spine Surgery, Sx=Symptoms, Rx=Treatment, Mig=Migration, ASx=Asymptomatic, Gp=Group, Percut=Percutaneous, ALIF=Anterior Lumbar Interbody Fusion, Ortho=Orthopedic, Pts=Patients, Chg=Change, Pack=Packing, ION=Intraoperative Navigation, Lam=Laminectomy, Microdisc=Microdiscectomy , OLIF=Oblique Lumbar Interbody Fusion, SympNI=Sympathetic Nerve Injury, Periop=Perioperative, LDD=Lumbar Degenerative Disease, Spondy=Spondylolisthesis, Deg Scoli=Degenerative Scoliosis, DiscLBP=Discogenic Low Back Pain, ASD=Adjacent Segment Disease, V=Vertebral, Fx=Fractures, SympNI=Symptomatic Nerve Injury, N=Nerve, Mos=Months, XLIF=Extreme Lateral Interbody Fusion, ODI=Oswestry Disability Index, NASS=North American Spine Society, VAS=Visual Analog Scale, OR=Operations, Retro=Retrospective, Th=Thoracic, Lum=Lumbar, Instru=Instrumented, Gp=Group,PPF=Posterior Percut Fusion, Endo=Endoscopy both groups (i.e., 58.4 for XLIF vs. 56.1 for OLIF.), and they showed comparable clinical findings, operative times, EBL, number of operated levels, and follow-up durations.

LC for MI Anterior Lumbar Interbody Fusions (ALIF)

Mirza *et al*. (2022) found the LC included the first 25 - 30 cases out of 120 MI ALIF performed with posterior percutaneous instrumentation at the L45 and L5S1 levels (2010-2018) [Table 1].[8] The 1st 25 patients demonstrated more adverse events, including a higher 32% incidence of major vascular injuries requiring primary repair/packing vs. a 0% incidence in the 2nd group of 25 patients. Additionally, although the 1st 30 patients had higher average estimated intraoperative EBL, the average operative times were comparable for the 1st 30 and the latter 90 patients.

Satisfied with In-Person/Intraoperative Mentoring Provided by Manufacturers, Academia, or Well-Trained Colleagues Could Limit the LC for MI Spine Surgery

Although some companies/manufacturers of spinal instrumentation provide "mentors" to directly scrub/supervise spine surgeons performing new operations, how many spine surgeons request and/or receive this "help"? Most likely, inexperienced spine surgeons return home and begin performing these procedures. Typically, they don't consult experts or well-trained colleagues at surrounding academic/non-academic institutions, particularly if they are in competing groups or specialties (i.e., neurosurgery vs. orthopedics) or at surrounding institutions.

Risks and Remediation of Spinal Surgeons' Learning Curves for MI Spine Operations

Several authors focused on the risks to patients during spine surgeons' LC for different MI spine procedures, and potential remediation maneuvers [Table 1].[2,4,10,11] Recommendations for remediation have included; practicing on cadavers/models, using virtual/augmented/surgical simulators, and, most critically, in-person/intraoperative surgeon-mentors [Table 1].[2,4,10,11] In 14 studies involving 966 patients, Sclafani *et al*. (2014) found the overall LC for performing 5 types of MI fusions required 20-30 cases/procedures (i.e., "... MIS lumbar decompression procedures, TLIF, percutaneous pedicle screw insertion, laparoscopic ALIF, and MIS cervical procedures); their 11% complication rate (i.e., 109/966) was largely attributed to dural tears, implant malposition, nerve injuries, and non-unions [Table 1].[10] In 2017, Epstein pointed out that the LC rates varied markedly for TLIF (i.e., between 10-44 cases), while other procedures' LC warranted 20-30 cases (i.e., MI laminectomy, MI cervical, MI ALIF, Thoracic/Lumbar Pedicle Screw Techniques) [Table 1].[2] Epstein concluded that; "...better oversight measures and or mentoring programs could limit the morbidity/AE occurring during these "LC" in the future." Sharif *et al*. (2018) observed a 30-case LC frequency for different MI spine operations that involved less "familiar anatomy", reduced "tactile feedback", and often new instrumentation (i.e., endoscopes) [Table 1].[11] Their recommendation included the use of; "Structured training with cadavers and lots of practice, preferably while working under the guidance of experienced surgeons.". Kimchi *et al*. (2020) concluded after performing 230 open vs. MI thoracic/lumbar spine operations that; "The main challenge facing the MIS community is constructing an education program for MIS surgeons in order to reduce the learning curve-induced complications" [Table 1].[4] They further concluded; "Advancement of educational aids for MIS skill improvement including spine models, virtual and augmented reality aids, and surgical simulators may reduce the learning curve of spine surgeons".

CONCLUSION

Twelve studies showed that the LC for different MI lumbar spine operations varied markedly (i.e., 10-44 cases) [Table 1].[1-12] Shouldn't spine surgeons avail themselves of more routine in-person/intraoperative mentoring or other "educational simulation modalities" to limit the risks to patients during the LC for these varied spine procedures?

Ethical approval

Institutional Review Board approval is not required.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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