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Describing the spine surgery learning curve during the first two years of independent practice

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Abstract

Retrospective cohort study

To characterize the learning curve of a spine surgeon during the first 2 years of independent practice by comparing to an experienced colleague. To stratify learning curves based on procedure to evaluate the effect of experience on surgical complexity.

The learning curve for spine surgery is difficult to quantify, but is useful information for hospital administrators/surgical programs/new graduates, so appropriate expectations and accommodations are considered.

Data from a retrospective cohort (2014–2016) were analyzed at a quaternary academic institution servicing a geographically-isolated, mostly rural area. Procedures included anterior cervical discectomy and fusion, posterior cervical decompression and stabilization, single and 2-level posterior lumbar interbody fusion, lumbar discectomy, and laminectomy. Data related to patient demographics, after-hours surgery, and revision surgery were collected. Operative time was the primary outcome measure, with secondary measures including cerebrospinal fluid leak and early re-operation. Time periods were stratified into 6 month quarters (quarter [Q] 1–Q4), with STATA software used for statistical analysis.

There were 626 patients meeting inclusion criteria. The senior surgeon had similar operative times throughout the study. The new surgeon demonstrated a decrease in operative time from Q1 to Q4 (158 minutes–119 minutes, $P < .05$); however, the mean operative time was shorter for the senior surgeon at 2 years (91 minutes, $P < .05$). The senior surgeon performed more revision surgeries (odds ratio [OR] 2.5 [95% confidence interval [CI] 1.7–3.6]; $P < .001$). Posterior interbody fusion times remained longer for the new surgeon, while laminectomy surgery was similar to the senior surgeon by 2 years. There were no differences in rates of cerebrospinal fluid leak (OR 1.2 [95% CI 0.6–2.5]; $P > .05$), nor reoperation (OR 1.16 [95% CI 0.7–1.9]; $P > .05$) between surgeons.

A significant learning curve exists starting spine practice and likely extends beyond the first 2 years for elective operations.

Abbreviations: ACDF = anterior cervical discectomy and fusion, CI = confidence interval, CSF = cerebrospinal fluid, MIS = minimally invasive stabilization, OR = odds ratio, Q = quarter, TLIF = transforaminal lumbar interbody fusion.

Keywords: complication rate, operating time, spine surgery, spine surgical learning curve, surgical complexity, surgical experience

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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1. Introduction

Practice is an integral component in developing mastery of any technical skill, including surgical excellence.[1] Although practice is gained throughout residency training, in spine surgery (where there is significant risk of irreversible neurologic injury), true independence is not gained until the beginning of a surgeon's own practice. Examining the relationship between early-career, technical surgical ability and patient outcomes is challenging.[2] Prior efforts to evaluate the first years of spine surgical practice, or alternatively newer techniques, demonstrate a linear relationship between surgical volume and improved patient outcomes.[3–5] Many of these efforts use surrogate measures such as operative time, complication rate, re-operation rate, and intra-operative blood loss to describe the learning curve. To our knowledge, a direct comparison of these measures between junior and senior spine surgeons at the same institution has not been previously published. Knowing what to expect as a new spine surgeon could help psychologically, but also from an institutional planning perspective.

The purpose of this study is to characterize the spine surgical learning curve by directly comparing the outcomes of a novice independent surgeon (ie, in the first 2 years of practice) to those of a senior surgeon operating within the similar patient population, using similar surgical (open) technique over the same period of time. Secondarily, we sought to stratify learning curves based on procedure performed to evaluate the effect of surgical experience on surgical complexity.

2. Materials and methods

This study took place at a quaternary Canadian academic hospital, where there are only 2 adult orthopaedic spine surgeons servicing a rather large, mostly rural community. A retrospective cohort design was chosen and utilized a surgical registry of all patients who underwent orthopaedic spine surgery by 1 of 2 spine surgeons (a novice surgeon and a senior surgeon) between October 2014 and October 2016. An institutional review board at the Nova Scotia Health Authority approved the methodology of the study (Research Ethics Board File #1022544). Both surgeons used primarily open approaches over the study period for all pathologies addressed for the exception of microdiscectomy surgery which was done under microscope visualization.

All patients from the registry were initially assessed for inclusion. Patients were then excluded from the study if they did not have one of the following surgical interventions: anterior cervical discectomy and fusion (ACDF), posterior cervical spine stabilization, single-level transforaminal lumbar interbody fusion (TLIF), 2-level TLIF, discectomy, and laminectomy. Removal of instrumentation, hematoma evacuation, and irrigation and debridement were included to account for postoperative complications. Additional exclusion criteria included the following: deformity surgery from T12-pelvis, deformity surgery from T4-pelvis, pedicle subtraction osteotomy, cervical vertebrectomy, thoracic/lumbar vertebrectomy, minimally invasive stabilization (MIS), anterior lumbar interbody fusion, coccygectomy, and odontoid surgery. The timing and frequency of these surgeries varies dramatically and were therefore excluded as they would not provide a sufficient sample size to compare outcomes of interest. Surgeries that were performed by both surgeons concurrently were also excluded as direct comparison of outcome variables would not be applicable to the study.

Independent study variables included: age, sex, body mass index, American Society of Anaesthesiologists classification, Worker's Compensation Board insurance claim, after hours surgery, revision surgery, and surgical category. The primary outcome measure was total operative time (measured in minutes). The secondary outcome measures were cerebrospinal fluid (CSF) leak and reoperation rate.

The relationship between total operative time and operating surgeon was examined to assess the learning curve for ACDF, posterior cervical spine stabilization, single-level TLIF, 2-level TLIF, discectomy, and laminectomy. The 2 year study period was divided into 4, 6-month quarters for each surgeon to assess if the effect of learning on surgical time was nonlinear. Multiple linear regression analysis was used to determine the categorical effect of time and surgical experience on total operative time while controlling for patient covariates, with an interaction effect between surgeon and time to account for different learning rates between the 2 surgeons. Subgroup analyses were completed for single-level TLIF and laminectomy patients. Chi-squared analyses were used to identify differences in rates of reoperation, CSF leakage, and revision surgery. Repeat operation was defined as any subsequent operation that was performed within the same 2 year period. Revision operation referred to any prior operation that was performed outside of the 2 year window.

Table 1

Clinical characteristics of the total patient population.

Variables	Senior surgeon N=297 (%)	Novice surgeon N=329 (%)	Total population N=626 (%)
Age (yr)			
Mean, SD	62.1 (14.8)	56.6 (16.7)	59.2 (16.1)
Sex			
Male	153 (51.5)	173 (52.6)	326 (52.1)
Female	144 (48.5)	156 (47.4)	300 (47.9)
BMI (kg/m^2)			
Mean, SD	30.5 (6.7)	30.1 (6.1)	30.3 (6.4)
Missing	2 (0.67)	8 (2.43)	10 (1.6)
ASA classification			
1 to 2	198 (66.7)	236 (71.7)	434 (69.3)
3 to 4	99 (33.3)	93 (28.3)	192 (30.7)
Insurance status			
WCB claim	15 (5.1)	17 (5.2)	32 (5.1)
No claim	278 (93.6)	305 (92.7)	583 (93.1)
Missing	4 (1.3)	7 (2.1)	11 (1.8)
Surgery category			
ACDF	8 (2.7)	25 (7.6)	33 (5.3)
Posterior C-spine	18 (6.1)	30 (9.1)	48 (7.7)
1-level TLIF	126 (42.4)	89 (27.1)	215 (34.4)
2-level TLIF	35 (11.8)	24 (7.3)	59 (9.4)
Discectomy	28 (9.4)	100 (30.4)	128 (20.5)
Laminectomy	53 (17.8)	44 (13.4)	97 (15.5)
Other	29 (9.8)	17 (5.2)	46 (7.4)
After hours			
Yes	14 (4.7)	48 (14.6)	62 (9.9)
No	283 (95.3)	281 (85.4)	564 (90.1)
Revision			
Yes	107 (36.0)	61 (18.5)	168 (26.8)
No	190 (64.0)	268 (81.5)	458 (73.2)

SD=standard deviation; BMI=body mass index; ASA=American Society of Anaesthesiologists; TLIF=transforaminal lumbar interbody fusion; ACDF=anterior cervical discectomy and fusion; Other=removal of hardware, evacuation of hematoma, irrigation and debridement; WCB=Workers Compensation Board

3. Results

There were 945 patients identified within the registry and following the application of the exclusion criteria, a total of 626 patients were eligible for inclusion. Baseline patient characteristics for the senior surgeon and the novice surgeon are summarized in Table 1.

Outcome analysis for the surgical learning curve related to operative time is detailed within Table 2. For the overall patient population, the senior surgeon demonstrated similar overall operative times across each of the 4 time periods, with no evidence of differences in operating time when compared to quarter (Q)1 ($P>.05$). The novice surgeon significantly reduced their overall operative time from Q1 (157.6 min) to Q4 (119.0 min) (Fig. 1). However, the mean operative time was significantly longer for the novice surgeon than the senior surgeon at the end of the 2 year study period (119 minutes vs 90.8 minutes). These are adjusted estimates based on the interaction model detailed later.

Evaluation of single-level TLIF surgeries considered both patient characteristics (Table 3) and the outcome analysis for operative time (Table 2). The senior surgeon continued to demonstrate an operative time that was statistically similar in each quarter relative to Q1 ($P>.05$). The novice surgeon improved their overall operative time as they gained experience (Fig. 2), but remained significantly longer than the Q1 reference group at all time points ($P<.05$). This was also reflected by

Table 2

Mean operative time across two year period.

Operating surgeon	Operative time (min)	95% Confidence interval	*P*-value
Total population			
Senior surgeon			
Q1*	91.6	81.5 to 101.7	N/A
Q2	103.2	93.1 to 113.3	.112
Q3	97.4	87.6 to 107.2	.421
Q4	90.8	81.1 to 100.6	.910
Novice surgeon			
Q1	157.6	148.1 to 167.2	<.001
Q2	133.8	124.2 to 143.5	<.001
Q3	127.0	117.3 to 136.8	<.001
Q4	119.0	110.0 to 128.0	<.001
Single level TLIF population			
Senior surgeon			
Q1*	107.9	94.5 to 121.3	N/A
Q2	110.0	97.6 to 122.3	.823
Q3	113.8	101.5 to 126.1	.529
Q4	100.9	87.1 to 114.8	.468
Novice surgeon			
Q1	186.9	171.4 to 202.4	<.001
Q2	150.7	132.8 to 168.6	<.001
Q3	145.4	130.4 to 160.4	<.001
Q4	134.6	117.8 to 151.5	.018
Laminectomy population			
Senior surgeon			
Q1*	73.6	55.9 to 91.2	N/A
Q2	81.1	62.2 to 100.0	.575
Q3	79.3	58.2 to 100.4	.683
Q4	73.5	58.5 to 88.6	1.000
Novice surgeon			
Q1	114.7	87.6 to 141.7	.012
Q2	90.7	73.6 to 107.9	.172
Q3	92.9	75.3 to 110.5	.117
Q4	67.4	52.0 to 82.8	.609

N/A = not applicable.
* Reference group.

comparing the mean operative time of each surgeon over the 2 year time period (134.6 minutes vs 100.9 minutes).

Results for laminectomy patients are also detailed in Tables 2 and 3. Once again, the senior surgeon demonstrated a relatively constant operative time across quarters ($P > .05$, when compared to Q1 reference group), and the novice surgeon reduced operative time as experience was gained (Fig. 3). In fact, there was no significant difference between the overall operative time of the novice surgeon and the Q1 reference group other than in the first quarter ($P > .05$). Overall, for the 2 year study period, the mean operative time for the novice surgeon was less than that of the senior surgeon (67.4 minutes vs 73.5 minutes).

Table 4 highlights difference in rates for CSF leakage, reoperations, and revision surgeries (ie, prior operations performed outside the 2 year time interval) for the 2 surgeons. There were no differences in rates of CSF leakage (odds ratio

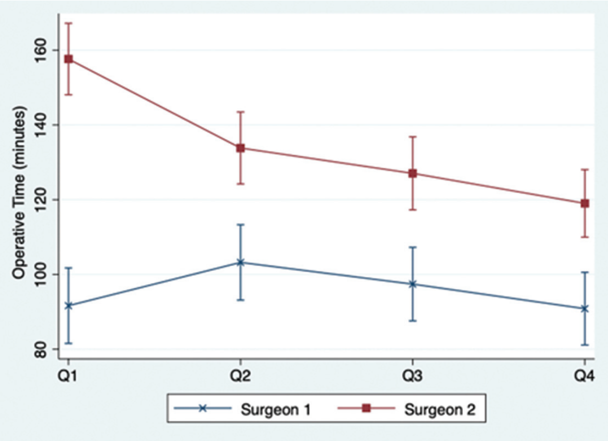

Figure 1. Total population mean operative time over two year period (adjusted time estimates from the interaction model). Q = quarter.

Table 3

Clinical characteristics of the subsets of patient populations.

TLIF patient population			
Variables	**Senior surgeon N=126 (%)**	**Novice surgeon N=89 (%)**	**Total population N=215 (%)**
Age (yr)			
Mean, SD	62.65 (13.5)	64.6 (11.7)	63.45 (12.8)
Sex			
Male	58 (46.0)	37 (41.6)	95 (44.2)
Female	68 (54.0)	52 (58.4)	120 (55.8)
BMI (kg/m^2)			
Mean, SD	30.9 (7.0)	30.8 (6.5)	30.9 (6.8)
ASA classification			
1 to 2	79 (62.7)	61 (68.5)	140 (65.1)
3 to 4	47 (37.3)	28 (31.5)	75 (34.9)
Insurance status			
WCB claim	8 (6.3)	3 (3.4)	11 (5.1)
No claim	115 (91.3)	84 (94.4)	199 (92.6)
Missing	3 (2.4)	2 (2.2)	5 (2.3)
After hours			
Yes	2 (1.6)	4 (4.5)	6 (2.8)
No	124 (98.4)	85 (95.5)	209 (97.2)
Revision			
Yes	49 (38.9)	22 (24.7)	71 (33.0)
No	77 (61.1)	67 (75.3)	144 (67.0)
Laminectomy patient population			
Variables	**Senior surgeon N=53 (%)**	**Novice surgeon N=44 (%)**	**Total population N=97 (%)**
Age (yr)			
Mean, SD	66.2 (13.0)	66.1 (12.9)	66.2 (12.9)
Sex			
Male	34 (64.2)	34 (77.3)	68 (70.1)
Female	19 (35.8)	10 (22.7)	29 (29.9)
BMI (kg/m^2)			
Mean, SD	30.5 (5.8)	30.1 (4.6)	30.3 (5.3)
ASA classification			
1–2	37 (69.8)	32 (72.7)	69 (71.1)
3–4	16 (30.2)	12 (27.3)	28 (28.9)
Insurance status			
WCB claim	3 (5.6)	2 (4.5)	5 (5.2)
No claim	49 (92.5)	40 (90.9)	89 (91.8)
Missing	1 (1.9)	2 (4.5)	3 (3.0)
After hours			
Yes	1 (1.9)	4 (9.1)	5 (5.2)
No	52 (98.1)	40 (90.9)	92 (94.9)
Revision			
Yes	14 (26.4)	5 (11.4)	19 (19.6)
No	39 (73.6)	39 (88.6)	78 (80.4)

ASA = American Society of Anaesthesiologists, BMI = body mass index, SD = standard deviation, TLIF = transforaminal lumbar interbody fusion, WCB = Workers Compensation Board.

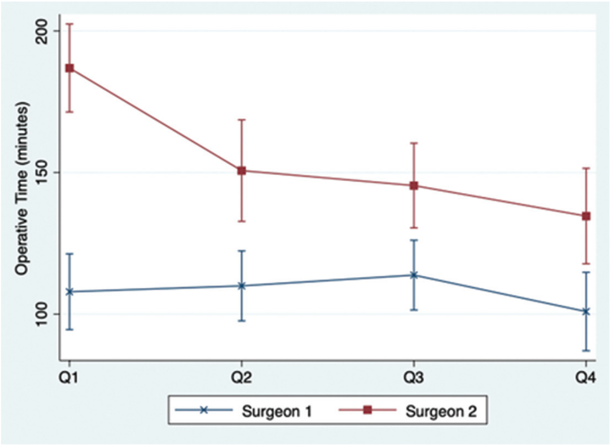

Figure 2. Single level TLIF mean operative time over two year period (adjusted time estimates from the interaction model). Q = quarter, TLIF = transforaminal lumbar interbody fusion.

[OR] 2.5; 95% confidence interval [CI]: [0.6, 2.5]; $P > .05$) or reoperation (OR 1.16; 95% CI: [0.7, 1.9]; $P > .05$), but the senior surgeon was more likely to perform revision surgeries (OR 2.5; 95% CI: [1.7, 3.6]; $P < .001$).

A multiple regression model was built to predict the effect of individual surgeon (senior vs novice) on surgical time, and to investigate how that difference changed over time. An interaction model was built to model the surgical times for each surgeon at each of the 4 time points independently, controlling for surgical group, age, sex, body mass index, American Society of Anaesthesiologists class, revision status, and initial diagnosis. Table 5 contains the estimated differences in surgical times across each of the 4 time points. At each time point, the senior surgeon's operating time is shorter, but the difference is greatly reduced after the first 6 months, dropping from a 63 minute difference in Q1 (95% CI: [49,77]) to a 25 minute difference in each of the 3 subsequent time intervals (95% CI: [11,39]). The overall fit was good (adjusted $R^2 = 0.48$), though some variation in surgical time remains after adjustment.

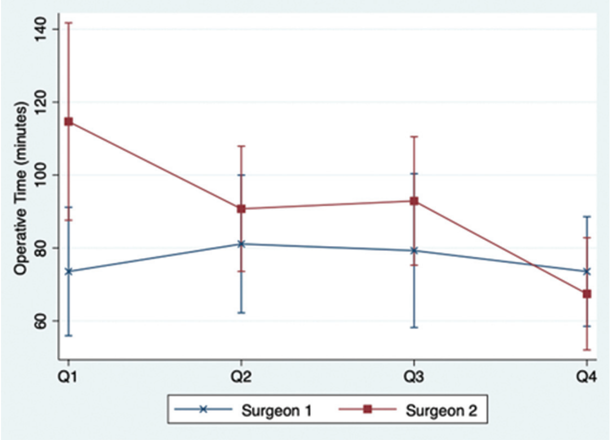

Figure 3. Laminectomy mean operative time over two year period (adjusted time estimates from the interaction model). Q = quarter.

Table 4

Rates of CSF leakage, revision surgery, and reoperation.

Variables	Senior surgeon N=297 (%)	Novice surgeon N=329 (%)	Total population N=626 (%)
CSF leakage			
Yes	13 (4.4)	17 (5.2)	30 (4.8)
No	283 (95.3)	308 (93.6)	591 (94.4)
Missing	1 (0.3)	4 (1.2)	5 (0.8)
Reoperation			
Yes	35 (11.8)	34 (10.3)	69 (11.0)
No	262 (88.2)	295 (89.7)	557 (89.0)
Revision surgery			
Yes	107 (36.0)	61 (18.5)	168 (26.8)
No	190 (64.0)	268 (81.5)	458 (73.2)

CSF = cerebrospinal fluid.

4. Discussion

Although the learning curve has been fairly extensively studied in other surgical fields, such as adult[6] and pediatric general surgery,[7,8] as well as other subspecialities within orthopaedic surgery,[9,10] it has yet to be fully examined in spine surgery. This learning curve is important to understand for novice spine surgeons beginning independent practice. Novice surgeons may use this information to tailor their case difficulty and set appropriate expectations for the trajectory of their surgical outcome measures as they gain experience.

Previous studies have focused on the learning curve of specific operations, such as ACDF,[5,11] lateral lumbar interbody fusion,[12] and TLIF.[13,14] There have also been similar studies on specific techniques, such as MIS,[3,15] pedicle screw insertion,[16] osteotomies,[17] and endoscopic interlaminar lumbar decompressions.[18] Most of these studies examine a senior spine surgeon's experience with a new technique or operation, where an accelerated learning curve would be expected when compared to a novice surgeon. Only 1 study examined the learning curve of a novice surgeon during the beginning of their independent surgical career.[11] However, this study examined a single operation, ACDF, and did not compare to a control group or an experienced surgeon.

Overall, mean operative time decreased by 24.5% by the end of the 2 year period, but there was a larger decrease in operative time in less technically challenging operations (ie, 41.2% reduction for laminectomies compared to 28% for single-level TLIF). The largest reductions occurred during the transition from the first quarter to the second quarter. In this first 6 months of practice, operative time decreased by 15.1%, 19.4%, and 20.9% for all patients, single-level TLIF, and laminectomy groups, respectively. This was followed by a relatively steady decrease in operative time over the next 2 quarters for all patients and the single-level

Table 5

Adjusted differences in surgical times between the novice and senior surgeon.

Quarter	Difference	LCL	UCL	*P*-value
Q1	63.17	48.96	77.37	<.001
Q2	25.27	11.00	39.54	.001
Q3	25.09	11.41	38.76	<.001
Q4	25.20	11.78	38.63	<.001

TLIF group, but there was a significant decrease in operative time of 27.4% from quarter 3 to quarter 4 in the laminectomy group. The majority of the improvement from Q1 to Q2 can likely be attributed to a novice surgeon gaining confidence in the surgical team and operating room staff, operating in a new environment, and honing their skills with surgical exposure and operative planning. The late improvement from Q3 to Q4 for the laminectomy group may be explained by the smaller sample size (n = 44) for that patient population, or it could also represent the novice spine surgeon achieving surgical proficiency as it is a less technically challenging operation.

Mayo et al[11] demonstrated a similar 25.6% reduction in operative time when comparing the first 125 patients to the second 125 patients during a novice spine surgeon's experience with ACDF. There was a smaller reduction of 7.7% in operative time when comparing the second 125 patients to the third 124 patients in the final patient cohort. They concluded that the surgical learning curve was overcome by case 75 in their study. Similarly, Nandyala et al[14] displayed a 21% reduction in operative time during MIS TLIF procedures when comparing the first 33 patients to the second 32 patients. These reductions in operative time are in keeping with what was demonstrated by the surgical learning curve displayed in this current study.

Intraoperative complications such as rates of CSF leak (4.4% vs 5.2%) and postoperative complications such as reoperation (11.8% vs 10.3%) were similar. These findings are in keeping with the previous literature, as rates of intraoperative complications are low amongst junior surgeons and experienced surgeons learning new techniques. Wang et al[18] examined a trained surgeon's experience with endoscopic intralaminar lumbar decompression. They found an intraoperative complication rate of 12.5% in the first 10 patients. This decreased to 10% in the second 10 patients, and 0% in the final 10 patients. Similarly, experienced surgeons demonstrated constant rates of CSF leak (6%) with MIS TLIF when comparing the initial 33 patients to the subsequent 32 patients.[14] Park et al[16] established that a novice surgeon will achieve proficiency in the complete containment within the pedicle on postoperative CT scan during the free-hand pedicle screw insertion technique by the 312th screw. Similarly, Mayo et al[11] assessed a novice surgeon's experience with ACDF for degenerative cervical spondylosis. The first 374 patients of the surgeon's career were split into early (125), middle (125), and late (124) cohorts. Operative time decreased from 85.8 minutes to 59.5 minutes, estimated blood loss decreased from 99.7 mL to 46.8 mL, and arthrodesis rate increased from 93.6% to 100%.

In the current study, the included procedures were mostly elective and of lesser complexity. This likely represents the early practice patterns of a novice surgeon as many complex surgeries (deformity surgery, osteotomies, vertebrectomies, and uncommon surgeries) are completed with the assistance of a senior spine surgeon in the beginning of a novice surgeon's career. Although the procedures were less complex this allowed for truly independent comparison between the spine surgeons. This singular surgical experience may not be representative of all new spine surgical practices, however this is representative of a novice spine surgeon's early career in a Canadian academic centre.

The novice surgeon was more likely to perform after hours of surgery. This illustrates that the novice surgeon is more likely to take more time into the early evening hours to finish the surgical case load for the day. This is important information for administrators and quality assurance representatives to understand and thus allocate appropriate resources to support this subtle increased burden on the healthcare system.

The retrospective nature of this review introduces potential bias despite statistical controlling. Also, a limited comparison between a junior and senior surgeon, limits the generalizability of the results. Further, many new surgeons are trained to use more minimally invasive techniques which will make future comparisons such as these difficult but also may impair the generalizability of the current study. It is difficult to find opportunities, however, when these comparisons would be possible where surgeons have very similar practices.

Functional scores, patient reported outcomes, and patient satisfaction were not considered as outcomes within this study which are central to assessing efficacy differences between surgeons. Additionally, although reoperations were captured within the 2-year study period, late complications such as pseudarthrosis and implant failure were not accounted for individually.

In summary, expectations as a new spine surgeon could help individuals psychologically, but there are also important implications from an institutional resource allocation perspective. A significant learning curve exists within the first 2 years of a novice spine surgeon's career, but substantial improvements in operative time can be expected as experience is gained. The surgical learning curve likely extends beyond the first 2 years of practice for most elective operations. Novice spine surgeons may accelerate through the surgical learning curve at a quicker pace with elective operations that are not as technically demanding, such as a laminectomy. Despite the surgical learning curve, novice spine surgeons are safe, as evidenced by similar rates in surgical complications.

Author contributions

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