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Original Article

Learning curve of microendoscopy-assisted minimally invasive transforaminal lumbar interbody fusion: 65 consecutive cases of one surgeon

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Abstract: Objective: To evaluate the learning curve of microendoscopy-assisted minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) performed by one senior surgeon. Methods: A total of 65 patients suffering from lumbar degenerative disease underwent single-level microendoscopy-assisted MIS-TLIF. Piecewise regression analysis using R statistical software was performed to define the turning point of learning curve (early and plateau phase). Perioperative evaluations included surgical duration, intraoperative fluroscopic time and blood loss, postoperative analgesic usage and ambulatory time. Clinical outcome assessments involved visual analogue score (VAS) for back and leg, Japanese Orthopaedics Association score (JOA), Oswestry disability index (ODI) and modified MacNab criteria. All these indicators, as well as complication incidence and interbody fusion (Birdwell classification) between both phases were compared. Results: The asymptote of learning curve was reached following previous 21 cases. Comparing latter 44 cases with first 21 cases, surgical duration (178.9 minutes *versus* 195.5 minutes), intraoperative fluroscopic time (53.2 seconds *versus* 77.5 seconds), blood loss (184.0 ml *versus* 205.5 ml), postoperative analgesic usage (43.0 mg *versus* 73.6 mg) and ambulatory time (2.1 days *versus* 2.6 days) revealed significant differences (all $P<0.05$). While at 20 months postoperation, VAS-back (0.8 *versus* 0.8), VAS-leg (0.7 *versus* 0.5), JOA (25.0 *versus* 25.0), ODI (12.2 *versus* 12.0), perfect or good assessment based on modified MacNab criteria (20/21 *versus* 43/44) and interbody fusion rate of grade I (18/21 *versus* 37/44) were nearly the same (all $P>0.05$). There were 5 complications (23.7%) and 10 complications (22.7%) at early and latter phase respectively, also showing no statistical significance ($P>0.05$). Conclusions: The turning point of this surgeon's learning curve for microendoscopy- assisted MIS-TLIF is achieved at the 21st case. Patients at its both phases acquire similar clinical outcomes, while latter patients can get additional advantages.

Keywords: Minimally invasive surgery, transforaminal lumbar interbody fusion, fixed-diameter endoscopy, learning curve

Introduction

Minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) has been demonstrated as a preferred alternative to the open surgery due to various advantages, such as less iatrogenic soft tissue injury, minimized neural retraction and reduced hospital stay, while acquiring similar clinical outcomes compared with open procedure [1-3]. Hence, it gains more popularity in recent years [4, 5]. However, common inherent difficulties for new learners in mastering technically demanding MIS-TLIF include limited surgical field, greater demand of eye-hand coordination, reduced tactile feedback and more manipulation finesse [6]. So the need to understand factors characterizing proficiency in its procedures becomes paramount, benefiting surgeons' learning of this surgical technique [7]. Meanwhile, attempting a new surgical procedure after comprehending its learning curve may avoid repeated and unnecessary errors [1]. To the best of our knowledge, some articles assessing the learning curve of MIS-TLIF using expandable dilator have been reported [1, 3, 6, 7], however, there have been few researches

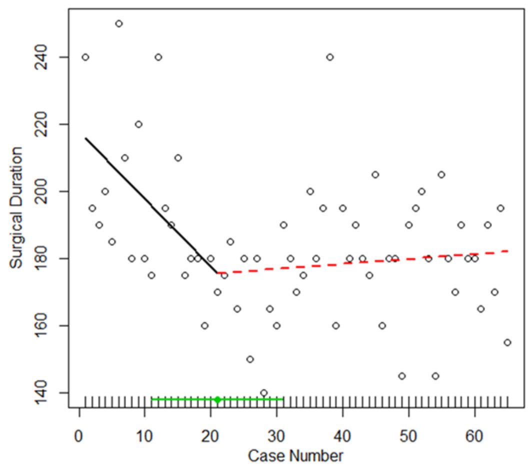

Figure 1. Graph of the learning curve with the turning point at the 21st case based on surgical duration plotted against case number.

focusing on fixed-diameter microendoscopy-assisted MIS-TLIF up to now. This study aimed to define the learning curve of one senior surgeon's single-level microendoscopy-assisted MIS-TLIF based on multiple parameters consisting of perioperative indicators, clinical outcomes and radiologic assessment.

Patients and methods

General data

From January 2010 to September 2014, sixty-five consecutive patients with unilateral neurological symptom were included in this retrospective study. Inclusion criteria were as follows: single responsible level; lumbar disc herniation with spinal instability; lumbar spinal canal stenosis with segemental instability; lumbar spondylolisthesis (less than Meyerding Grade II) [2, 6, 8]. While exclusion criteria were as follows: multiple responsible levels; severe spinal deformities; previous spinal instrumentations; spinal tumor pathologies or infections; acute spinal fractures; laboratory signs of hematologic disorders [2]. All included patients were refractory to conservative treatments, such as analgesic and functional rehabilitation exercise for at least six weeks. When hospitalized, they had detailed neurologic, as well as radiologic evaluations, involving lumbar static (anterior-posterior and lateral) and dynamic (flexion-extension) plain films, computed tomography (CT) and/or magnetic resonance imaging (MRI). In this series, all operations were performed by one senior surgeon, who has been practicing on spinal surgeries for more than 20 years and has achieved sufficient clinical training. Meanwhile, the same operation team, including the experienced first assistant (associate professor) and scrub nurse also participated in all operations in this series. In this study, informed consents were obtained from all individual participants prior to inclusion in this study.

Surgical procedure

Following general anesthesia, patient was evenly positioned prone on the radiolucent table. Under fluroscopic guidance, pedicle images of operated vertebraes were confirmed and then four corresponding paracentral transverse incisions were made to insert Jamshidi needle (one for canal decompression with the length of 2.0 cm, three for pedicle screw insertion with the length of 1.5 cm). It was first placed at the lateral margin of pedicle image (at three or nine o'clock position) and then slowly advanced into its contralateral margin along pedicle route. Inner stylet of Jamshidi needle was removed to allow kirschner wire to be inserted into pedicle. Dilators were sequentially placed over each other through the decompression incision, and then fixed working cannula with 20-mm diameter was inserted at the symptomatic side. Ipsilateral partial facetectomy and laminotomy, along with removal of ligamentum flavum were performed under microendoscopy to accomplish adequate neural decompression. Following discectomy and preparation of end plates, appropriate interbody cage filled with autologous bone and remaining bony particles were packed into intervertebral space medially. Pedicle screws and rods were then inserted through incisions percutaneously. Bilateral compression was applied before final tightening of the screw-rod construct. Finally, closure in layers was performed following wound haemostasis and irrigation.

Postoperative management

The drainage tube was removed at 24 hours postoperatively. Adequate administrations of non-steroid anti-inflammatory analgesics, as well as intravenous fluids were used to relieve pain and maintain circulation stability. In order to prevent deep vein thrombosis, antithrombotic compression stocking and intermittent foot

Table 1. Linear regression analysis

	Coefficient	Standard error	*t value*	*p* value	R^2
Early Group	-2.052	0.778	-2.638	0.016	0.268
Latter Group	0.134	0.222	0.603	0.550	0.009

R^2 Coefficient of Determination.

pump were initiated within several hours following surgery, when motion of bilateral lower extremities improved, active ambulation was also encouraged.

Parameter assessment

Perioperative parameters, including surgical duration, intraoperative blood loss and fluroscopic time, postoperative ambulatory time and analgesic usage were recorded. All cases were followed up for at least 20 months postoperatively and monitored for clinical parameters, involving complications and clinical outcomes. In this study, complications were categorized into minor and major parts. Minor complications include superficial wound infection, urinary infection, pneumonia, mild delirium state, transient angina pectoris attack or digestive tract ulcer. While major complications include location fault of operated level, anterior wall penetration of operated vertebrae, dural tear, haematoma compression, non-relieved or worsening neurological deficit. Clinical outcomes were assessed based on paper-form visual analogue score (VAS) for back and leg, Japanese Orthopaedics Association score (JOA) and Oswestry disability index (ODI) by patients themselves through the assistance of one assessor, with another scrutator available for adjudication. Collected data were accurately uploaded to computer and double-checked by both assessor and scrutator, who were blinded to included cases. Modified MacNab criteria was also applied for patients' self-evaluation of surgical outcomes. Besides, interbody fusion was evaluated based on CT image at 20 months postoperatively using the Birdwell classification [9].

Mathematical modeling and statistical analysis

All included patients were arranged sequentially according to their operation date, and piecewise regression analysis performed by R statistical software was used to determine the turning point of learning curve based on surgical duration. Its underlying premise assumed that the line of best fit in a scatterplot comprises 2 (or more) straight lines connected at the turning point(s) [6]. Mathematical algorithm introduced by Muggeo was applied to estimate the turning point and its 95% confidence limits [10]. In the learning curve graph based on surgical duration plotted against case number, cases prior to the turning point were considered at early phase of the learning curve (early group), while the following cases were deemed at its plateau phase (latter group). Statistical analysis was performed using SPSS version 21.0. Comparisons on continuous variables (expressed as mean ± standard deviation) intergroups and intra-group were tested by independent and paired *t*-test, respectively. Chi-squared test was utilized to compare categorical data. In this study, statistical significance was defined as $P<0.05$.

Results

According to piecewise regression analysis, the turning point was achieved following previous 21 cases. For the first group of 21 cases, gradual decrease of their surgical duration was observed. Thus, they represented early phase of the learning curve. For the following 44 cases, their surgical duration was seen comparably stable, depicting the learning curve's plateau phase (**Figure 1**). Linear regressions of both phases were established based on surgical duration plotted against case number (**Table 1**). Coefficient of early phase showed statistical difference ($P<0.05$), indicating proficiency of surgical manipulation was harvested gradually. On the contrary, coefficient of plateau phase revealed no statistical difference ($P>0.05$), demonstrating comparable stability of operational competency for the senior surgeon.

No case was converted to open surgery during operation. For preoperative data between early and latter group, there revealed no statistical difference ($P>0.05$, **Tables 2** and **4**). However, latter group was superior than early group in terms of perioperative parameters, including surgical duration, intraoperative fluroscopic time and blood loss, postoperative analgesic usage and ambulatory time ($P<0.05$, **Table 3**). At final follow-up, when comparing VAS-back,

Table 2. Demographic data

	Early group (21 cases)	Latter group (44 cases)	*p* value
Age (year-old)	59.3 ± 12.2	57.1 ± 13.1	0.520
Gender (male:female)	10:11 (47.6%:52.4%)	23:21 (52.3%:47.7%)	0.726
Body mass index (kg/m^2)	23.9 ± 1.9	23.3 ± 1.7	0.177
Preoperative diagnosis			
Disc herniation with instability	4 (19.0%)	7 (16.0%)	1.000
Canal stenosis with instability	8 (38.1%)	13 (29.5%)	0.113
Spondylolisthesis	9 (42.9%)	24 (54.5%)	0.378
Operated level			
L3/4	1 (4.8%)	3 (6.8%)	1.000
L4/5	18 (85.7%)	33 (75%)	0.509
L5/S1	2 (9.5%)	8 (18.2%)	0.591
Comorbidity	10 (47.6%)	25 (56.8%)	0.487

Table 3. Perioperative parameters

	Early group (21 cases)	Latter group (44 cases)	*p* value
Surgical duration (minutes)	195.5 ± 24.6	178.9 ± 18.6	0.004
Fluroscopic time (seconds)	77.5 ± 13.0	53.2 ± 4.8	0.000
Intraoperative blood loss (ml)	205.5 ± 31.7	184.0 ± 26.2	0.005
Postoperative analgesic usage (mg)	73.6 ± 16.5	43.0 ± 5.2	0.000
Postoperative ambulatory time (days)	2.6 ± 0.5	2.1 ± 0.6	0.001

Table 4. Clinical and radiologic parameters

	Early group (21 cases)	Latter group (44 cases)	*p* value
VAS (back)			
Preoperation	5.3 ± 1.1	4.9 ± 1.8	0.276
Final follow-up	0.8 ± 0.8*	0.8 ± 0.9*	0.875
VAS (leg)			
Preoperation	6.3 ± 1.0	5.6 ± 1.6	0.065
Final follow-up	0.5 ± 0.7*	0.7 ± 0.9*	0.420
JOA			
Preoperation	13.1 ± 2.4	14.4 ± 3.9	0.176
Final follow-up	25.0 ± 2.8*	25.0 ± 2.8*	0.953
ODI			
Preoperation	(52.4 ± 10.5)%	(50.4 ± 15.1)%	0.583
Final follow-up	(12.0 ± 8.7)%*	(12.2 ± 9.2)%*	0.934
Modified MacNab			
Perfect or good	20 (95.2%)	43 (97.7%)	1.000
Fair or poor	1 (4.8%)	1 (2.3%)	1.000
Complication			
Major	3 (14.2%)	3 (6.8%)	0.607
Minor	2 (9.5%)	7 (15.9%)	0.754
Interbody fusion of Grade I	18 (85.7%)	37 (84.1%)	1.000

VAS visual analogue scale, JOA Japanese Orthopaedics Association score, ODI Oswestry disability index. *Comparing with preoperation, *P*<0.05.

VAS-leg, JOA and ODI between both groups, there demonstrated no significant difference (*P*>0.05, **Table 4**), while compared with preoperative data, all these clinical indicators showed statistical significance (*P*<0.05, **Table 4**). According to modified MacNab criteria, the number of cases ranking excellent or perfect between both groups was nearly the same, revealing no statistical significance (*P*>0.05, **Table 4**). Based on Bridwell classification, both groups exhibited similar interbody fusion rate of Grade I (*P*>0.05, **Table 4**). **Figure 2** shows one case at plateau phase of the learning curve.

Complication rate between both groups showed no statistical significance (*P*>0.05, **Table 4**). There were 3 major complications in either group respectively. For Case 6, the anterior cortical wall of operated vertebrae was penetrated by kirschner wire with no surrounding organ injured. For Case 9, the operated level was located falsely at the beginning and then corrected. Case 14 suffered


A
B
C
D
E
F
G
H
I

Figure 2. Preoperative radiographs of a 62 year-old female suffering from progressive back pain and neurological intermittent claudication for 10 years (VAS-back: 5, VAS-leg: 6, JOA: 15, ODI: 60%), demonstrating lumbar spinal canal stenosis and segmental instability at L4-5 level (A-F). Microendoscopy-assisted MIS-TLIF achieved adequate canal decompression via the left approach, and patient's symptoms relieved significantly following surgery (VAS-back: 0, VAS-leg: 1, JOA: 25, ODI: 10%). Postoperative radiographs and CT scan revealed satisfactory interbody fusion (G-I).

from intraspinal haematoma because of incomplete haemostasis, revealing worsening neurological deficit and demanding emergency surgery. Case 35 was found dural tear with no postoperative symptom. Neurological symptom of Case 41 was not relieved postoperatively, even after enhanced medications, so another canal decompression surgery using percutaneous endoscopy was performed. Unilateral decreased muscle strength of Case 49 was observed after surgery, while following conservative medications, muscle strength got recovery. Totally, 9 minor complications (early: 2, latter: 7) were observed in this series. There were 2 cases of mild delirium state, 2 cases of transient angina pectoris attack and 2 cases of urinary infection. Three remaining patients fitted each of following categories: superficial wound infection, pneumonia and transient digestive tract ulcer. All of them received successful medications.

Discussion

In this study, all operations were performed under fixed-diameter microendoscopy, leading to further decreased iatrogenic injury compared with expandable dilator because of only 20-mm diameter working cannula and blunt dilatation of incision [11]. However, delicate surgical manipulations in constrained tubular working channel may be difficult to learn and master, thus hindering surgeons from adopting it, so it is of great clinical importance to elucidate the learning curve of microendoscopy-assisted MIS-TLIF. This study first confirmed that the first 21 cases represent its early phase, less than other associated researches [1, 3, 6]. It may be explained by the massive experiences acquisition on microendoscopic discectomy, microendoscopic canal or nerve root decompression, as well as percutaneous hardware implantation, previously. We attempted first MIS, namely microendoscopic discectomy in 2003, and more than 650 cases had been performed in subsequent several years. We also initiated percutaneous screw-rod construct in 2009. Thus, performing microendoscopy-assisted MIS-TLIF is believed not so difficult after mastering aforementioned surgical skills. Meanwhile, familiarizing operating steps by the first assistant, scrub nurse also accelerates surgical efficiency [1, 6]. However, it should be noted that the amount of operated cases per month may also impose influence on final result, for more surgical practices would lead to more rapid mastery of surgical technique for surgeons. There were only 1.2 operated cases per month in this series, less than other associated studies [3, 6, 7, 12]. If more cases were able to be operated within each month, less than 21 cases representing the learning curve's early phase would be observed. Following experience acquisition of surgeons, they are able to determine the desired fluoroscopy images more efficiently, so that fluroscopic time is shortened, benefiting both surgeons and patients. With the reductions of surgical duration and iatrogenic injury, intraoperative blood loss is also able to be decreased. The above improvements contribute to less analgesic usage and earlier ambulation postoperatively as well.

As surgical duration is the most representative parameter used to assess learning curve due to its conformance to the surgeon's experience with the technique, this study firstly profiled the graph based on surgical duration plotted against case number to evaluate the learning process [13]. However, shortened surgical duration is not considered to always correlate with successful clinical outcomes for patients, so one surgeon's true mastery of surgical technique is not only dependent on one indicator, but also other multiple aspects, including complication, readmission, patient satisfaction and long-term outcome [12]. Besides surgical duration, this study also compared functional scores and patients' self-evaluation of surgical outcomes 20 months after surgery, as well as complications between early and plateau phase. Agreeing with the results reported by previous studies [1, 6], all these parameters did not reveal significant difference, demonstrating clinical outcome and complication rate of microendoscopy-assisted MIS-TLIF were not involved with surgeon's technical competency, thus its therapeutic efficacy and safety can be confirmed preliminarily. However, another research found that perioperative complications of MIS-TLIF occurred more often in the early period of surgeon's experience with this procedure [14]. For different individual surgeons, varying levels of surgical experiences acquisition through previous career practices, as well as heterogeneity of disease spectrum may explain this difference. In both phases of the learning curve depicted by this study, most complications were not involved with surgical technique and would be avoided if promptly observed and properly managed. The remaining ones were mainly contributed to technical imcompetence, especially during the process of neural decompression, so well preoperative preparation and meticulous intraoperative manipulation, including scrutinization of decompression segment and extent, as well as careful protection of dural sac and nerve root may be the best prophylaxis [15]. Once postoperative complications happen, conservative treatments, covering medication, physiotherapy and rehabilitation should be initiated as soon as possible for both major and minor ones, while revision surgery is necessitated if worsening outcomes following those treatments are observed.

As with most other ones, this study demonstrated that better intraoperative indicators, involving surgical duration, blood loss are harvested along with gradual increase of operated cases [3, 6, 7]. However, some researches find that the learning curve associated with minimally invasive lumbar fusion technique is steep [12, 16]. This difference may be also attributed to varying levels of surgeons' clinical experiences and comfort with the surgical procedure. With experience gathering during early phase, accuracy of pedicle screw placement, adequacy of canal decompression and whole workflow ergonomics can be improved in latter phase. At the end of learning curve's plateau phase in this series, surgical duration increased mildly, reflecting inclusion of more advanced cases. For there are two rate-limiting procedures associated with this surgical technique-thorough neural decompression and well end plate preparation [7], although more familiarity of anatomical structures under microendoscopy and enhanced manipulation experiences, including appropriate placement of working canal, maintenance of clear surgical field were obtained through initial cases, there still existed great challenges when operating on these difficult cases, thus surgical duration revealed no steady reduction.

In order to reduce potential deviations on final results, only single-level cases were included in this study, also one kind of microendoscopy and inner fixation system were solely used. Besides, surgeons participating in operations were not involved in analyzing clinical and radiologic outcomes, instead these parameters were evaluated by independent assessor and scrutator. However, drawbacks of this report should be acknowledged. First, only one surgeon of single medical institution was included, therefore, its clinical significance may not apply to all surgeons utilizing this surgical technique. Second, the surgeon also performed other kinds of minimally invasive spinal surgeries during this study span, such as microendoscopic discectomy, percutaneous endoscopic lumbar discectomy (approximately 12 operations per month). These techniques perhaps accelerated his surgical efficiency of microendoscopy-assisted MIS-TLIF [6]. Third, this study was associated with various disease spectrum, small sample size and short postoperative follow-up, thus bias may emerge. Measures taken to reduce these limitations consist of inclusion of single disease entity performed by more surgeons from multiple institutions, as well as application of larger sample size and longer postoperative follow-up.

Conclusion

Our study concluded that one senior surgeon's technical competency of microendoscopy-assisted MIS-TLIF was achieved following first 21 cases. Patients at both early and plateau phases of the learning curve acquired comparable clinical outcomes, while latter patients could additionally benefit from shortened surgical duration, decreased intraoperative fluroscopic time and blood loss, reduced postoperative analgesic usage and earlier ambulation after surgery.

Disclosure of conflict of interest

None.

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