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Minimally Invasive Transpedicular Screw Fixation: Review of 152 Cases in a Single Institution. Steep or Shallow Learning Curve?

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Abstract

Background In this study, we analyze our institutional experience and personal impressions using minimally invasive spine surgery (MISS) to describe our learning curve and how experience influenced different parameters of the surgical procedure.

Methods The study was conducted prospectively and included the first consecutive 152 patients treated with MISS techniques. Patient demographics, surgical data, length of hospital stay, and clinical outcome were reviewed. The cohort was divided into consecutive quarters. Comparison between the quarters and timeline analysis were made to assess the learning curve.

Results Only percutaneous transpedicular screw fixation was performed in 65 cases, minimally invasive transforaminal lumbar interbody fusion (MI-TLIF) in 70 cases, and vertebral body replacement in 4 cases. The average blood loss was 113.3, 115, 106.6, and 107.1 mL for each quarter. The average operative time was 155.0, 143.2, 134.5, and 133.8 minutes for the four quarters, whereas the average radiation exposure time was 105.4, 85.3, 46.2, and 45.2 seconds. Differences in the operative time and radiation exposure time between the first to third and the first to fourth quarters were statistically significant.

Conclusions Some advantages of MISS techniques could be observed with the very first cases and were not related significantly with the surgeon's experience with MISS. With the acquisition of more experience, some disadvantages of MISS techniques such as longer operative time and longer X-ray exposure can be substantially reduced. Surgical experience, familiarity of the team with the MISS instrumentation, and good patient selection are crucial for achieving all the benefits of MISS.

Keywords
- minimally invasive technique
- spine surgery
- pedicle screw
- radiation exposure
- learning curve

Introduction

During the last decade, various minimally invasive spine surgery (MISS) techniques have been developed with the aim to reduce approach-related soft-tissue trauma and its associated complications while achieving the clinical and radiologic outcomes of open techniques.[1–4] The MISS quickly proved as an alternative for a short-segment spinal pathology. With the evolution of modern MISS instrumentations, the possibilities for reduction, distraction, compression, and

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reclining on multiple levels increased substantially and MISS became a therapeutic option even for complex spinal pathologies, traumas, and deformities. However, there is still controversy regarding some possible disadvantages of MISS techniques, such as longer operating times, higher intraoperative radiation, a challenging learning curve,[2,3,5–7] and a potentially higher risk of cage and pedicle screw misplacements.[5]

The aim of this study is to analyze our institutional experience and personal impressions using MISS to describe our learning curve and how gaining experience influences different parameters of the surgical procedure.

Methods

This prospective study included 152 consecutive patients who underwent MISS performed by a single senior surgeon between April 2013 and December 2018. According to the protocol, patient demographics, type of pathology, type and number of implants used, blood loss, duration of surgery, radiation exposure, and length of hospital stay (LOS) were recorded. The outcome was measured by pre- and postoperative Visual Analog Scale (VAS) score and Oswestry Disability Index (ODI) questionnaire.

The cohort was divided into consecutive quarters (38 patients each). A comparison of the results for each quarter and timeline analysis was made to assess the learning curve of the MISS techniques and how the parameters of the surgical procedure changed over the time period. A Mann–Whitney *U* test was used to compare the parameters of the surgical procedure for the different quarters. The data were analyzed using the computer software IBM SPSS Statistics version 22.0.

A comparison between our institutional experience using MISS and the results from the literature review was made.

Results

In this series, 152 patients, comprising 70 women (46%) and 82 men (54%), were operated on. The average patient age at the time of surgery was 49 years (range: 17–81 years). The average follow-up was 1 year. The etiology of the pathology was traumatic in 65 cases, degenerative in 71 cases, oncologic in 8 cases, and infectious in 8 cases. Twenty-four patients were obese (body mass index [BMI] > 30), and in 15 cases MISS was used for revision surgery. Treated levels ranged from Th5 to S1. The number of treated vertebrae ranged between two and six (►**Table 1**).

Table 1 Spinal levels treated and number of segments included

Thoracic level	14 patients
Lumbar level	103 patients
TL junction (T11–L2)	35 patients
Short segment (4 screws)	67 patients
Short segment (6 screws)	49 patients
Short segment (5 screws)	3 patients
Long segment stabilizations (≥4 levels)	33 patients

Table 2 Duration of surgery for each quarter and for the whole series

1st quarter	2nd quarter	3rd quarter	4th quarter	All ($n = 152$)
155.0 min	143.2 min	134.5 min	133.8 min	141.6 min

Table 3 Radiation exposure for each quarter and for the whole series

1st quarter	2nd quarter	3rd quarter	4th quarter	All ($n = 152$)
105.4 s	85.3 s	46.2 s	45.2 s	70.1 s
10.1 mGy	8.2 mGy	4.4 mGy	4.4 mGy	6.8 mGy

Only percutaneous transpedicular screw fixation was performed in 65 cases, minimally invasive transforaminal lumbar interbody fusion (MI-TLIF) in 70 cases and vertebral body replacement in 4 cases. Augmented screws were used in 13 cases. In total, 817 screws and 86 cages were implanted.

The operative time ranged from 60 to 180 minutes, with an average of 141.6 minutes for the series (►**Table 2**). The difference in the operative time between the first and third quarters was statistically significant ($p = 0.0268$), as was for the first and last quarters ($p = 0.0136$).

The average radiation exposure time was 70.1 seconds (range: 30–121 seconds) or 6.8 mGy (range: 3.0–12.2 mGy; ►**Table 3**). Mean time in minutes per screw was 20.8 minutes for procedures with transpedicular stabilization only. Mean radiation exposure was 14.1 seconds or 1.4 mGy per screw.

The difference in radiation exposure time between the first and the third quarters was statistically significant ($p = 0.0073$) as was for the first and last quarters ($p = 0.0082$).

The operative blood loss was between 50 and 200 mL (average: 110 mL). There were no intraoperative complications or conversions to open surgery. The LOS ranged from 2 to 7 days (average: 6.0 days), and the mean time until leaving the bed was 1.8 days (►**Table 4**). The difference in blood loss

Table 4 Blood loss and length of hospital stay (LOS) for each quarter and for the whole series

	1st quarter	2nd quarter	3rd quarter	4th quarter	All ($n = 152$)
Average blood loss (mL)	113.3	115.0	106.6	107.1	110.0
Average LOS (d)	5.9 d	6.3 d	5.4 d	6.5 d	6.02d

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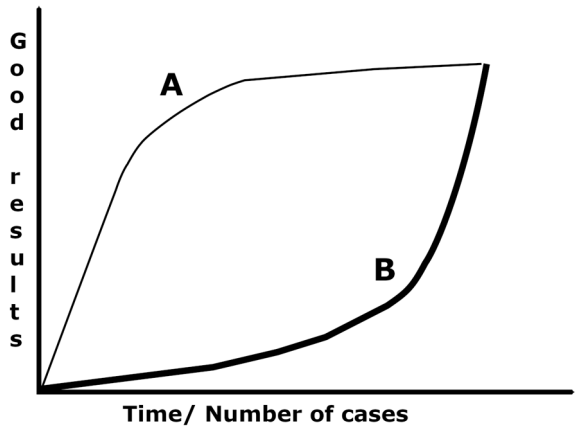

Fig. 1 Learning curve. Curve A: steep learning curve. Good results (performance) are achieved quickly, for a short period of time (small number of cases). Curve B: shallow learning curve. Good results (performance) are achieved for a longer period of time (more cases are required to obtain good results).

and LOS for different quarters was not statistically significant.

The VAS score was reduced from 7.9 points preoperatively to 2.1 points at 1 year postoperatively. The ODI score improved from a preoperative severe disability (mean: 52.1%) to moderate disability (25.2%) at 1 month up to a minimum disability (mean 17.9%) at 1 year postoperatively. The difference in the functional outcome for the different quarters was not statistically significant.

In two cases, there was a dural tear intraoperatively. No perioperative infections were observed. In four patients, there was malposition of a screw, but only one was symptomatic. Cage subsidence was observed in three cases. In three patients with severe osteoporosis, loss of correction and screw failure were observed during the follow-up.

Discussion

In surgery, a learning curve is defined as the time taken and/or the number of cases required by a surgeon to obtain good results and to become proficient, for example, to reduce operative time, to reduce estimated blood loss, and to reduce the morbidity, adverse events, and complication rate. The literature is not conclusive whether the learning curve of MISS should be defined as steep or shallow as both are used with opposite meanings.[8,9] The term steep learning curve is often used in informal language to mean a difficult, challenging learning process. However, most sources and our own interpretation define a learning curve as a plot showing proficiency as a function of the number of repetitions, so a steep increase would mean that quick increment of the necessary skills and performance are achieved in fewer repetitions[9,10] (►**Fig. 1**, curve A). Consecutively, good results are obtained for a shorter period of time—with a smaller number of cases. Shallow learning curve, on the other hand, would require more time and more cases to reach good results and performance (►**Fig. 1**, curve B). Regarding the learning curve for MISS, we believe it is multifactorial and should not be defined simply as steep or shallow. It would be more useful and informative if we analyze the learning curve for different parameters of the surgical procedure separately.

As discussed in the literature, the advantages of MISS are less muscle and tissue disruption, minimized blood loss, reduced rate of surgical site infection, reduced recovery period, shortened hospital stays, and higher patient satisfaction.[1–4]

This is not surprising given that MISS employs techniques such as tubular retraction or minimal skin incisions, which preserve the contralateral ligament and bony attachments of paraspinal muscles, thereby reducing potential bleeding. The minimal muscle dissection and bone removal also will reduce complications attributed to blood clot accumulation and tissue fluid accumulation.[5] Several studies demonstrate statistically significant or highly significant reductions in intra-/perioperative blood loss in the MI-TLIF cohorts compared with their open TLIF groups ranging from mean values of 100 to 456 mL in the MI-TLIF cohorts versus 450 to 961 mL in the open TLIF group.[6,7] Villavicencio et al[2] reported lower estimated blood loss (163 mL) and shorter hospitalization (3 days) in MI-TLIF compared with open TLIF (366.8 mL and 4.2 days). In our group, the estimated blood loss was 50 to 200 mL, which is comparable with those reported in the literature and supports the finding that minimally invasive techniques significantly reduce tissue damage and intraoperative blood loss. Decreased exposure surface and limited muscle disruption also significantly reduce the opportunity for bacteria entry and hence surgical site infection.[3] In our series, the average LOS was 6.02 days. Patients were verticalized after an average of 1.8 days. No operative infection was observed. Other studies also show a significantly shorter time to ambulation in the MISS groups compared with the open technique groups.[11] Eckman et al[12] discharged 73% of their 1,114 patients on the day of the MI-TLIF, meaning 808 of their patients were mobilized on the day of the surgery. In seven studies, LOS was significantly shorter in the MI-TLIF cohorts with a mean LOS of 3 to 9.3 days compared with the open TLIF groups with a mean LOS of 4.2 to 12.5 days.[4,7]

Minimized surgical trauma and reduced paraspinal muscle dissection are likely responsible for the significant reduction in postoperative VAS and ODI scores in the MISS cohorts versus the open technique cohort. In a meta-analysis by Vazan et al,[1] 11 studies reported VAS on follow-up of 1.0 to 3.4 in the MI-TLIF group and 1.2 to 7.5 in the open TLIF group. A meta-analysis by Phan et al reported a mean difference in VAS back pain scores of 0.4 points lower for MI-TLIF, and an ODI score 2.2 points lower for MI-TLIF compared with open TLIF.[5] In our group, the mean preoperative VAS score was 7.9 and the average postoperative score was 2.1 at the last follow-up. The ODI score improved from the average preoperative of 52.1% to 17.9% at the last follow-up.

Contemplating on the learning curve of MISS, we analyzed how the above-mentioned parameters of the surgical procedure changed with more surgical experience. In our series, there was no significant difference in the average operative blood loss and mean LOS between the four consecutive

quarters (►**Table 4**). There was also no significant difference in functional outcome—the mean postoperative VAS score was 0.2 lower and the mean postoperative ODI score was 1.1 lower for the later 76 cases. That is why we believe that the benefits discussed not only are indisputable and evidence based but also can be achieved with the very first cases without significantly depending on the surgeon's experience with the MISS technique. Therefore, the learning curve of MISS for these parameters of the surgical procedure should be defined as steep because favorable results are achieved at the very beginning and after only a few repetitions.

However, there is still controversy regarding the possible disadvantages of MISS—longer operating times, higher intraoperative radiation, and a potentially higher risk of cage and pedicle screw misplacements. There are studies that show significantly shorter operation times in the open surgery groups (90–250 minutes) compared with the minimally invasive group (135–375 minutes).[1] No difference in length of surgery is shown by Schizas et al,[6] Brodano et al,[13] and other studies. Phan et al,[5] in a systematic review of the literature, also found no significant difference in operation time between the MI-TLIF and open TLIF cohorts (median duration of 185 minutes for minimally invasive compared with 186 minutes for the open procedures). Chang et al also found no significant difference in ODI and operation time between MIS and conventional open surgery.[14] Wang et al,[15] however, found a significantly shorter operating time for MI-TLIF (127 ± 25 minutes) compared with open TLIF (168 ± 37 minutes) in obese patients. Concerning radiation exposure, most of the studies have shown significantly longer radiation exposure times during MISS surgery (range: 45.3–106 seconds) compared to conventional open procedures (range: 24–39 seconds).[2,15,16] Phan et al, in their literature review and meta-analysis, also reported that the X-ray exposure time was significantly higher in the MI-TLIF group compared with the open TLIF group by 37 seconds.[5]

In our opinion, these results are due to the relatively shallow learning curve associated with MISS techniques for these parameters of the surgical procedure. In our group, the mean operative time was 141.6 minutes, which is comparable with results from other literature reports. However, we found a decrease in operative time with the increasing surgical experience of our team—mean duration of surgery for the first quarter of 38 cases was 155 minutes, 143.21 minutes for the second quarter, 134.4 and 133.7 minutes, respectively, for the third and last quarters (►**Fig. 2**). This means that we needed ~76 cases to achieve optimal reduction of our time for surgery. The operative time for the third and fourth quarters was significantly shorter than that for the first 38 cases.

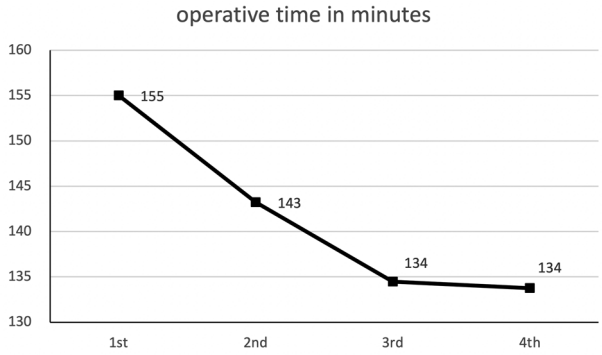

Fig. 2 Operative time in minutes for the 1st, 2nd, 3rd, and 4th quarter of patients.

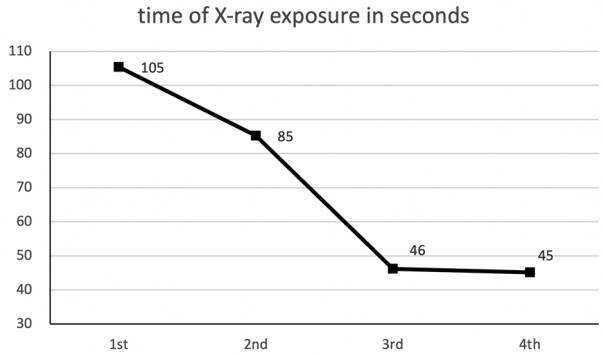

Fig. 3 Time of X-ray exposure in seconds for the 1st, 2nd, 3rd, and 4th quarter of patients.

Regarding the X-ray exposure in our series, the average time of radiation exposure was 70.05 seconds or 6.84 mGy (►**Table 3**), which seems to be significantly different from that of the open surgery techniques. However, the exposure time also showed a significant decrease with the increasing surgical proficiency—average 105.4 seconds or 10.06mGy for the first quarter of patients, 85.25 seconds or 8.26 mGy for the second, 46.2 seconds or 4.44 mGy and 45.18 seconds or 4.35mGy for the third and last quarters (►**Fig. 3**). We have achieved 50% decrease of radiation exposure, with the results of the latter two quarters comparable to those of conventional surgery.

Comparing the results of the four consecutive groups, it is evident that there was an important decrease in the duration of surgery and radiation exposure between the first three quarters and almost no difference between the third and fourth group of patients. There was no significant difference in functional outcome regarding the VAS and ODI scores when comparing the four timeline groups. On the other hand, most of the complications were observed in the first two quarters—4 cases of screw malposition, 2 dural tears, 2 cases with loss of correction, and 2 cases with cage subsidence. One case with loss of correction and 1 case with cage subsidence were observed in the third quarter and no complications were observed for the last 38 patients.

Therefore, we can conclude that the learning curve for some parameters of the surgical procedure such as duration of surgery, intraoperative radiation, and a potentially higher risk of cage and pedicle screw misplacements should be defined as shallow, and acquisition of necessary skills, experience, and proficiency took ~76 cases in our series.

The improved efficiency could be explained with the increasing experience of the surgeon and the surgical team, which led to familiarity with the operative steps,

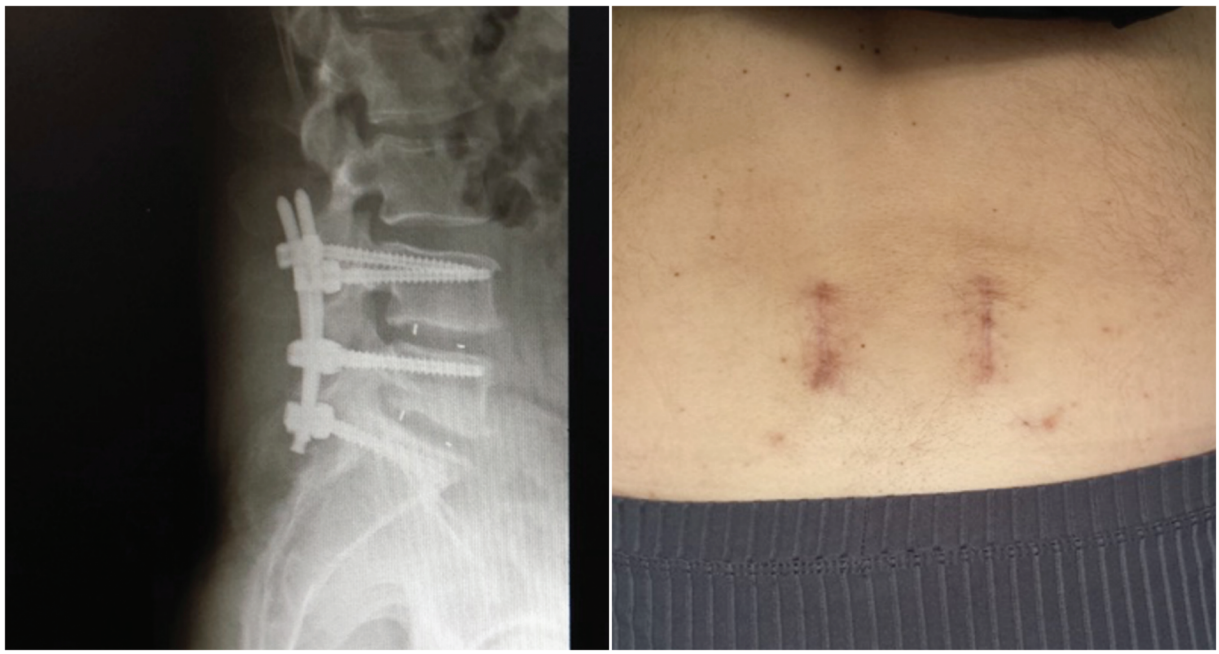

Fig. 4 Two-level transforaminal lumbar interbody fusion (TLIF) with two parallel to the midline skin incisions instead of multiple small incisions.

improvement in the workflow ergonomics, and evolution of the operative techniques. This is evident if we analyze the reduction of operative time and radiation exposure with gaining more surgical experience. For example, for the first quarter of patients, an average of 67 fluoroscopic shots per surgery were used compared with an average of 29.6 fluoroscopic shots per surgery for the third quarter, and 29 fluoroscopic shots per surgery for the fourth quarter. We can conclude that increasing the proficiency of the team over time led to more confidence of the surgeon, less need for fluoroscopic control, and consequently reduction of the operative time. This improvement of efficiency cannot be attributed only to the ameliorated skills and confidence of the surgeon. The better results came with the improvement of workflow and implementation of new operative techniques. For example, the use of two parallel to the midline covering two to three pedicle skin incisions instead of multiple small incisions for each pedicle (►**Fig. 4**) led to much better tactile sensation and anatomical orientation for the surgeon with a resulting significantly shorter operative and radiation exposure times.

Another example is the introduction of the "four-hand surgical technique." The surgical steps are not performed by one surgeon (Senior Surgeon) with the help of an assistant, but both surgeons work simultaneously and sequentially on the same pedicle screw sharing the different steps to save time. For example, surgeon 1 protects the k-wire and the soft-tissue retractors, and the second surgeon is tapping; then the second surgeon inserts the screw while the first one takes care of the k-wire. The "four-hand surgical technique," trained scrub nurse, and well-designed operative plan and ergonomics allowed a continuous workflow with significant reduction of time per screw and radiation exposure. Fifty-six cases of the latter two quarters were performed in this manner and this is probably one of the main reasons for the significant decrease of time of surgery and radiation exposure in comparison with the first two groups.

In our opinion, one of the most important factors for better results was the accurate patient selection. When analyzing our series, we observed that more of the cases were performed at the beginning of the time period—91 cases for the first half (from April 2013 to December 2015) and 61 cases for the second 3 years (from January 2016 to December 2018). In the second half of the study, better patient selection led to better results regarding complications, shorter time of ambulation, and shorter duration of surgery and radiation exposures. In selected pathologies, time of surgery and radiation exposure time were even shorter than the reported times for open techniques.

This conclusion is supported by other reports. For example, Schizas et al[6] found an average decrease of operative time by 1.8 hours (from 6.1 to 4.3 hours) when comparing the first and last third in their MI-TLIF series. In a study by Lee et al, the mean operative time in the early group was 187.2 minutes, decreasing significantly to 132.3 minutes in the later groups. Similarly, the mean fluoroscopy duration was 74.4 seconds in the early group, which decreased to a mean of 29.9 second in the later groups.[17]

Regarding our experience, we have to also emphasize that MISS might be particularly beneficial in obese patients with a BMI >30. In our group, MISS was used in 24 cases of obese patients. The mean operative time in these cases was 146.6 minutes compared with 142.8 minutes for the whole series. The average blood loss was 140 mL and the mean radiation exposure time was 73.2 seconds. Other studies also found less blood loss and lower complication rates, shorter operating time and hospital stay, and reduced local pain after MI-TLIF in obese patients.[1,15]

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Conclusion

Minimally invasive percutaneous spinal fixation techniques have some clear advantages, such as reduction of the iatrogenic intraoperative tissue trauma, thus minimizing blood loss and postoperative pain, and shortening the LOS. We believe that these soft tissue–related benefits can be observed in the initial cases and are not related significantly with the surgeon's experience with the MISS technique.

With the acquisition of more experience, some disadvantages of MISS techniques such as longer operative time and longer X-ray exposure can be substantially and significantly reduced and become comparable to open techniques.

Surgical experience, familiarity of the team with the MISS instrumentation, and good patient selection are crucial for achieving all the benefits of MISS techniques and make them a reasonable and less invasive alternative to conventional open surgery techniques.

Conflict of Interest
None declared.

References

1 Vazan M, Gempt J, Meyer B, Buchmann N, Ryang Y-M. Minimally invasive transforaminal lumbar interbody fusion versus open transforaminal lumbar interbody fusion: a technical description and review of the literature. Acta Neurochir (Wien) 2017;159 (06):1137–1146

2 Villavicencio AT, Burneikiene S, Roeca CM, Nelson EL, Mason A. Minimally invasive versus open transforaminal lumbar interbody fusion. Surg Neurol Int 2010;1(01):12

3 Walker CT, Xu DS, Godzik J, Turner JD, Uribe JS, Smith WD. Minimally invasive surgery for thoracolumbar spinal trauma. Ann Transl Med 2018;6(06):102

4 Wang J, Zhou Y, Zhang ZF, Li CQ, Zheng WJ, Liu J. Comparison of one-level minimally invasive and open transforaminal lumbar interbody fusion in degenerative and isthmic spondylolisthesis grades 1 and 2. Eur Spine J 2010;19(10):1780–1784

5 Phan K, Rao PJ, Kam AC, Mobbs RJ. Minimally invasive versus open transforaminal lumbar interbody fusion for treatment of degenerative lumbar disease: systematic review and meta-analysis. Eur Spine J 2015;24(05):1017–1030

6 Schizas C, Tzinieris N, Tsiridis E, Kosmopoulos V. Minimally invasive versus open transforaminal lumbar interbody fusion: evaluating initial experience. Int Orthop 2009;33(06): 1683–1688

7 Terman SW, Yee TJ, Lau D, Khan AA, La Marca F, Park P. Minimally invasive versus open transforaminal lumbar interbody fusion: comparison of clinical outcomes among obese patients. J Neurosurg Spine 2014;20(06):644–652

8 Lee JC, Jang H-D, Shin B-J. Learning curve and clinical outcomes of minimally invasive transforaminal lumbar interbody fusion: our experience in 86 consecutive cases. Spine 2012;37(18): 1548–1557

9 Sharif S, Afsar A. Learning curve and minimally invasive spine surgery. World Neurosurg 2018;119:472–478

10 Reichenbach DJ, Tackett AD, Harris J, et al. Laparoscopic colon resection early in the learning curve: what is the appropriate setting? Ann Surg 2006;243(06):730–735, discussion 735–737

11 Lau D, Lee JG, Han SJ, Lu DC, Chou D. Complications and perioperative factors associated with learning the technique of minimally invasive transforaminal lumbar interbody fusion (TLIF). J Clin Neurosci 2011;18(05):624–627

12 Eckman WW, Hester L, McMillen M. Same-day discharge after minimally invasive transforaminal lumbar interbody fusion: a series of 808 cases. Clin Orthop Relat Res 2014;472(06): 1806–1812

13 Brodano GB, Martikos K, Lolli F, et al. Transforaminal lumbar interbody fusion in degenerative disk disease and spondylolisthesis grade I: minimally invasive versus open surgery. J Spinal Disord Tech 2015;28(10):E559–E564

14 Chang F, Zhang T, Gao G, et al. Comparison of the minimally invasive and conventional open surgery approach in the treatment of lumbar stenosis: a systematic review and a meta-analysis. Ann Acad Med Singap 2017;46(04):124–137

15 Wang J, Zhou Y, Feng Zhang Z, Qing Li C, Jie Zheng W, Liu J. Comparison of the clinical outcome in overweight or obese patients after minimally invasive versus open transforaminal lumbar interbody fusion. J Spinal Disord Tech 2014;27(04): 202–206

16 Gu G, Zhang H, Fan G, et al. Comparison of minimally invasive versus open transforaminal lumbar interbody fusion in two-level degenerative lumbar disease. Int Orthop 2014;38(04): 817–824

17 Lee KH, Yeo W, Soeharno H, Yue WM. Learning curve of a complex surgical technique: minimally invasive transforaminal lumbar interbody fusion (MIS TLIF). J Spinal Disord Tech 2014;27(07): E234–E240