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Original Article

Effectiveness of Minimally Invasive Transforaminal Lumbar Interbody Fusion in Geriatric Patients

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SUMMARY

Background: Spinal fusion surgery is challenging for patients aged ≥ 65 years. Minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) is the mainstay of treatment for degenerative diseases. We conducted this retrospective study to explore the role of MIS-TLIF in patients aged ≥ 65 years.
Methods: We included patients who underwent MIS-TLIF between January 2014 and July 2021. Clinical outcomes were evaluated according to pain severity, medication use, activity, and work status. Comorbidities, MIS-TLIF levels, operation duration, intraoperative blood loss, length of hospital stay, and postoperative complications were analyzed and compared between patients aged ≥ 65 years and those aged < 65 years. A predictive model for short-term clinical outcomes was constructed using decision tree-based machine learning.
Results: A total of 138 patients were enrolled. More than 86% of the patients had excellent and good short-term clinical outcomes. The predictive model had excellent accuracy, with the area-under-the-curve values being > 0.9. Risk factors associated with favorable short-term clinical outcomes were length of hospital stay ≥ 7 days (odds ratio [OR] = 0.36, p = 0.042), operation duration ≥ 240 minutes (OR = 0.295, p = 0.018), and MIS-TLIF levels (OR = 0.522, p = 0.04). However, multivariate analysis results revealed that the effects of these factors were nonsignificant. The approach-related complication rate in the patients who underwent MIS-TLIF was approximately 5%.
Conclusion: According to our highly accurate predictive model, MIS-TLIF was effective in patients aged ≥ 65 years, with the corresponding short-term clinical outcomes being comparable to those observed in patient aged < 65 years.

1. Introduction

A geriatric population is commonly defined as individuals who are aged older than 65 years.[1] According to the United States Census Bureau report, the US geriatric population is expected to grow from 12% in 2000 to 20% in 2030.[2] In Taiwan, the geriatric population constituted > 7% of the total population in 1993, rendering Taiwan an "aging society"; the proportion of the geriatric population was predicted to increase to > 14% by 2018, rendering Taiwan an "aged society," and is expected to increase to > 20% by 2026, rendering Taiwan a "super-aged society."[3] The accelerated rate of aging in Taiwan is more than twice that of European countries and the United States.[4]

Aging-related problems include degenerative spinal diseases such as lumbar spinal stenosis, spondylolisthesis, and spinal deformity.[2] The volume of elective lumbar fusions performed in the United States increased by approximately 62.3% from 2004 to 2015, with the greatest increase (138.7%) being observed in the geriatric population.[5] Li et al. examined a cohort of 37,897 inpatients with degenerative spinal diseases in China and reported that the rate of spine surgery among patients aged ≥ 66 years increased from 10.48% in 2003 to 20.05% in 2016.[6] Similarly, a study in England over a 15-year period (from 1999 to 2013) reported a 2.8-fold increase in surgical procedures for degenerative spinal diseases among patients aged ≥ 60 years.[7]

The management of degenerative spinal diseases in geriatric patients is more complicated than that in younger patients because it necessitates the consideration of various factors, including bone quality, multiple deformities, continuous degeneration, and comorbidities.[1] Whether decompression combined with fusion is more effective than decompression alone in geriatric patients with degenerative spinal diseases is still controversial.[8] Minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) surgery can achieve optimal spinal decompression and fusion with less neural retraction, reduced blood loss, and decreased injury to paraspinal musculature compared with other surgical procedures.[9] A systematic review and meta-analysis of 12 studies demonstrated that MIS-TLIF was associated with a higher fusion rate, a greater improvement in patient-reported outcomes, and a higher complication rate in patients aged ≥ 65 years than in nonelderly patients.[10] However, the level of heter-

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ogeneity among the included studies was noted to be high. Accordingly, we conducted the present study to explore the role of MIS-TLIF in patients aged ≥ 65 years and to discuss factors associated with favorable outcomes and complications.

2. Materials and methods

2.1. Patient selection

This retrospective study included patients with degenerative lumbar diseases who underwent MIS-TLIF at a single institution in central Taiwan between January 2014 and July 2021. Our study was approved by the Institutional Review Board of National Taiwan University Hospital Yunlin Branch (No: 202109142RIND) in Taiwan. The inclusion criteria were as follows: (1) having severe back pain or leg pain with failed conservative treatment for more than 3 months; (2) receiving a diagnosis of degenerative lumbar stenosis with instability, lumbar spondylolisthesis, or recurrent lumbar disc with root compression; and (3) undergoing MIS-TLIF. The exclusion criteria were as follows: (1) having a surgical lumbar lesion related to infection, trauma, or neoplasm; (2) previously receiving lumbar surgical procedures such as lumbar spinal fusion, laminectomy, foraminotomy, or microdiscectomy; (3) receiving concurrent surgical procedures such as laminectomy, foraminotomy, or microdiscectomy for other lumbar segmental diseases during current MIS-TLIF; and (4) high-risk comorbidities such as heart failure (heart disease), liver cirrhosis (liver disease), and end-stage renal disease with hemodialysis (renal disease).

2.2. Surgical procedure of MIS-TLIF

Under general anesthesia, the patient was placed in the prone position. Fluoroscopic guidance with C-arm was used to localize the treated vertebras. After sterilized procedures, the two skin incisions with each 2.5 cm in length were made at paramedian vertical line. An expandable tubular retractor system (Pipeline; DePuy Synthes Spine, Raynham, MA, USA) was introduced to the facet joint by using the Wiltse's approach method. Laminofacetectomy and removal of the ligamentum flavum were done to exposure the spinal nerve roots. After discectomy, a polyetheretherketone interbody cage (ReBorn Essence; BAUI Biotech, New Taipei City, Taiwan) filled with autologous bone graft and demineralized bone matrix (Grafton; Medtronics, Memphis, TN, USA) was inserted into the empty disc space. After interbody fusion, the tubular retractor was removed, and bilateral percutaneous pedicle screw and rod system (Viper; DePuy Synthes Spine, Raynham, MA, USA) was inserted through the pedicle under the fluoroscopic guidance.

2.3. Assessments and follow-up of patients

Demographic data including age, gender, and comorbidities (e.g., hypertension, diabetes mellitus, heart disease, liver disease, and renal disease) were obtained at the time of enrollment. MIS-TLIF level, operation duration, intraoperative blood loss, length of hospital stay, and postoperative complications were evaluated for patients who underwent MIS-TLIF. All patients returned for regular postoperative follow-up assessments conducted at 3–6 months; the assessments involved evaluating changes in pain — as determined using a visual analogue scale (VAS) — and evaluating short-term clinical outcomes. The VAS was used to rate the intensity of pain from 0 ("no pain") to 10 points ("severe pain"). The short-term clinical outcomes during follow-up were rated as "excellent," "good," "fair," or "poor," depending on the severity of pain, the use of medication, activity, and work status (Table 1).[11,12] We conducted a logistic regression analysis in which a "favorable outcome" was defined as an excellent or good short-term clinical outcome, and an "unfavorable outcome" was defined as a fair or poor short-term clinical outcome.

2.4. Decision tree-based machine learning model

Decision tree-based machine learning was used to construct a predictive model for short-term clinical outcomes. The performance of the model was determined using receiver operating characteristic (ROC) curve analysis and the area under the ROC curve (AUC). A total of 1,000 decision trees were constructed. Moreover, 70% of the data were selected as the training set for each decision tree branch by using the bagging method; the remaining 30% served as the verification set. The derived decision tree had a maximum of 50 branches and had 1 sample at the terminal tree end. We combined the results derived by the 1,000 decision trees to estimate the relative weights of the variables and used the ensemble decision criteria to predict the short-term outcomes in patients who underwent MIS-TLIF.

2.5. Statistical analysis

We used descriptive statistics to analyze the patients' baseline characteristics. Ordinal and binary variables are presented as mean ± standard deviation and as percentage (%), respectively. We divided the patients into two groups according to age: (1) patients aged ≥ 65 years, and (2) patients aged < 65 years. The VAS, short-term clinical outcomes, radiological findings, and postoperative complications were compared between the two groups. The Student *t* test was used to assess the ordinal variables, and the chi-square test was used to test the binary variables. Dichotomous variables were evaluated using univariate and multivariate logistic regression analyses to elucidate factors associated with short-term clinical outcomes. All statistical analyses were performed using IBM SPSS Statistics for MacOS (version 26.0; IBM Corp., Armonk, NY, USA). Differences were considered statistically significant when the p was < 0.05.

3. Results

3.1. Demographic characteristics

We included a total of 138 patients who underwent MIS-TLIF

Table 1
Grading system for short-term clinical outcome.

Clinical outcome	Pain	The need of medication	Functional activity	Work status
Excellent	Total improvement except occasional back pain	None	Normal	Normal
Good	Marked improvement, occasional pain	Occasional	Minimal limitation	Return to work, although not at the same job activity
Fair	Some improvement	Frequent	Restriction	Limited
Poor	No change in symptoms or a worsening of the patient's condition	Oral use of narcotics	Incapacitated	Disabled

(Table 2). The patients' mean age was 66.12 ± 12.59 years. Women (58.7%) and individuals aged ≥ 65 years (65%) constituted a predominant proportion of the included patients. Regarding MIS-TLIF levels, 63.8% of the patients aged ≥ 65 years underwent ≥ 2-level MIS-TLIF, whereas 63.8% of the patients aged < 65 years underwent 1-level MIS-TLIF (p = 0.001). Finally, regarding comorbidities, a significantly higher proportion of the patients aged ≥ 65 years had a history of hypertension (p < 0.05) compared with the patients aged < 65 years.

3.2. Operation duration, length of hospital stay, and blood loss

The mean values derived for operation duration, intraoperative blood loss, and length of hospital stay in the patients aged ≥ 65 years and those aged < 65 years were 237 and 210 minutes (p = 0.054), respectively, 307 and 190 mL (p = 0.007), respectively, and 6.6 and 6 days (p = 0.265), respectively. Among these three factors, only intraoperative blood loss differed significantly between the patients aged ≥ 65 years and those aged < 65 years. Moreover, we compared the three factors between the two groups on the basis of MIS-TLIF level (Table 3). The results revealed that higher MIS-TLIF levels were associated with a longer operation duration, more intraoperative blood loss, and a longer length of hospital stay. However, the differences in operation duration, intraoperative blood loss, and length of hospital stay between the two groups on the basis of various MIS-TLIF levels did not reach statistical significance.

3.3. VAS scores and short-term clinical outcomes

The mean changes in preoperative and postoperative VAS scores in the patients aged ≥ 65 years and those aged < 65 years were 4.8 ± 1.3 and 4.7 ± 1.2, respectively. The differences between the two groups did not reach statistical significance (p = 0.5464). Approximately 86.2% of all patients had excellent or good short-term clinical outcomes (Table 4). In addition, 69 patients (86.3%) aged ≥ 65 years and 50 patients (86.2%) aged < 65 years had excellent or good short-term clinical outcomes, and the difference between two groups did not reach the significance (p = 0.994). A higher proportion of the patients aged ≥ 65 years had poor outcomes when compared with those aged < 65 years (5% vs. 1.7%), but the difference didn't reach the statistically significance (p = 0.304). However, a lower proportion of the patients aged ≥ 65 years had excellent outcomes when compared with those aged < 65 years (55% vs. 74.1%). The differences between the two groups reached statistical significance (p = 0.022).

3.4. Risk factors for favorable short-term clinical outcomes

To predict favorable short-term clinical outcomes among the patients, we conducted a logistic regression analysis using the following factors: age ≥ 65 years, intraoperative blood loss ≥ 200 mL, length of hospital stay ≥ 7 days, presence of comorbidities, post-

Table 2
Basic demographic data of the patients.

	All patients (N = 138)	Age ≥ 65 years (N = 80)	Age < 65 years (N = 58)	p value
Age (years)	66.12 ± 12.59	74.45 ± 6.18	54.62 ± 9.8	< 0.001
Female gender	81 (58.7%)	52 (65%)	29 (50%)	
Surgical levels				0.001
Three	26 (18.8%)	20 (25%)	6 (10.34%)	
Two	46 (33.3%)	31 (38.8%)	15 (25.9%)	
One	66 (47.8%)	29 (36.3%)	37 (63.8%)	
Comorbidities				
Diabetes mellitus	26 (18.8%)	14 (17.5%)	12 (20.7%)	0.731
Hypertension	71 (51.5%)	48 (60%)	23 (39.7%)	0.012
Renal disease	4 (2.9%)	3 (3.8%)	1 (1.7%)	0.309
Heart disease	18 (13%)	14 (17.5%)	4 (6.9%)	0.26
Liver disease	11 (8%)	7 (8.8%)	4 (6.9%)	0.979

Data presented as mean ± standard deviation or numbers (percentage).

Table 4
Short-term clinical outcomes in patients who underwent minimally invasive spinal fusion surgery.

Clinical outcome	All participants (N = 138)	Age ≥ 65 years (N = 80)	Age < 65 years (N = 58)	p value*
Excellent	87 (63%)	44 (55%)	43 (74.1%)	
Good	32 (23.2%)	25 (31.3%)	7 (12.1%)	
Fair	14 (10.1%)	7 (8.8%)	7 (12.1%)	
Poor	5 (3.6%)	4 (5%)	1 (1.7%)	
Excellent	87 (63%)	44 (55%)	43 (74.1%)	0.022
Others	51 (37%)	36 (45%)	15 (25.9%)	
Excellent or good	119 (86.2%)	69 (86.3%)	50 (86.2%)	0.994
Fair or Poor	19 (13.8%)	11 (13.7%)	8 (13.8%)	
Poor	5 (3.6%)	4 (5%)	1 (1.7%)	0.309
Others	133 (96.4%)	76 (95%)	57 (98.3%)	

* The comparisons of clinical outcome between patients aged ≥ 65 years vs. < 65 years.

Table 3
Comparisons of operation duration, intraoperative blood loss, and length of hospital stay between two groups for different minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) levels.

MIS-TLIF	Age ≥ 65 years	Age < 65 years	p value
One level			
Participants	29	37	
The length of operation time (minutes)	157.8 ± 24.2	169.6 ± 26.6	0.082
Intraoperative blood loss (ml)	108 ± 90	112.3 ± 90.6	0.482
The length of hospital day (days)	6.1 ± 4.3	5.8 ± 2.2	0.777
Two levels			
Participants	31	15	
The length of operation time (minutes)	254.6 ± 37.4	257.1 ± 33.6	0.842
Intraoperative blood loss (ml)	328.1 ± 206.1	306.7 ± 173.8	0.711
The length of hospital day (days)	6.7 ± 3.2	5.9 ± 1.4	0.358
Three levels			
Participants	20	6	
The length of operation time (minutes)	330.8 ± 22.2	367 ± 49.8	0.181
Intraoperative blood loss (ml)	543.8 ± 290.2	521.7 ± 370.1	0.879
The length of hospital day (days)	7.2 ± 1.6	7.5 ± 3.5	0.731

Data presented as mean ± standard deviation.

operative changes in VAS scores ≥ 5 points, operation duration ≥ 240 minutes, and the number of MIS-TLIF ≥ 2 levels. Our decision tree-based model revealed that the AUC scores for excellent, good, fair, and poor outcomes were 0.9059, 0.9238, 0.9804, and 0.997, respectively (Figure 1). This prediction model was noted to be accurate, with an AUC score of > 0.9.[13]

Our univariate analysis (Table 5) revealed that risk factors for favorable short-term clinical outcomes were length of hospital stay ≥ 7 days (odds ratio [OR] = 0.36, 95% confidence interval [CI]: 0.135–0.963, p = 0.042), operation duration ≥ 240 minutes (OR = 0.295, 95% CI: 0.108–0.808, p = 0.018), and the number of MIS-TLIF ≥ 2 levels (OR = 0.522, 95% CI: 0.281–0.971, p = 0.04). However, our multivariate analysis revealed that all seven factors were not significantly associated with favorable short-term clinical outcomes (Table 6).

3.5. Approach-related complications

Four patients (5%) aged ≥ 65 years and six patients (10.3%) aged < 65 years had postoperative complications. Three patients aged ≥ 65 years and two patients aged < 65 years had incidental durotomy with cerebrospinal fluid leakage. After dural repair, these five pa-

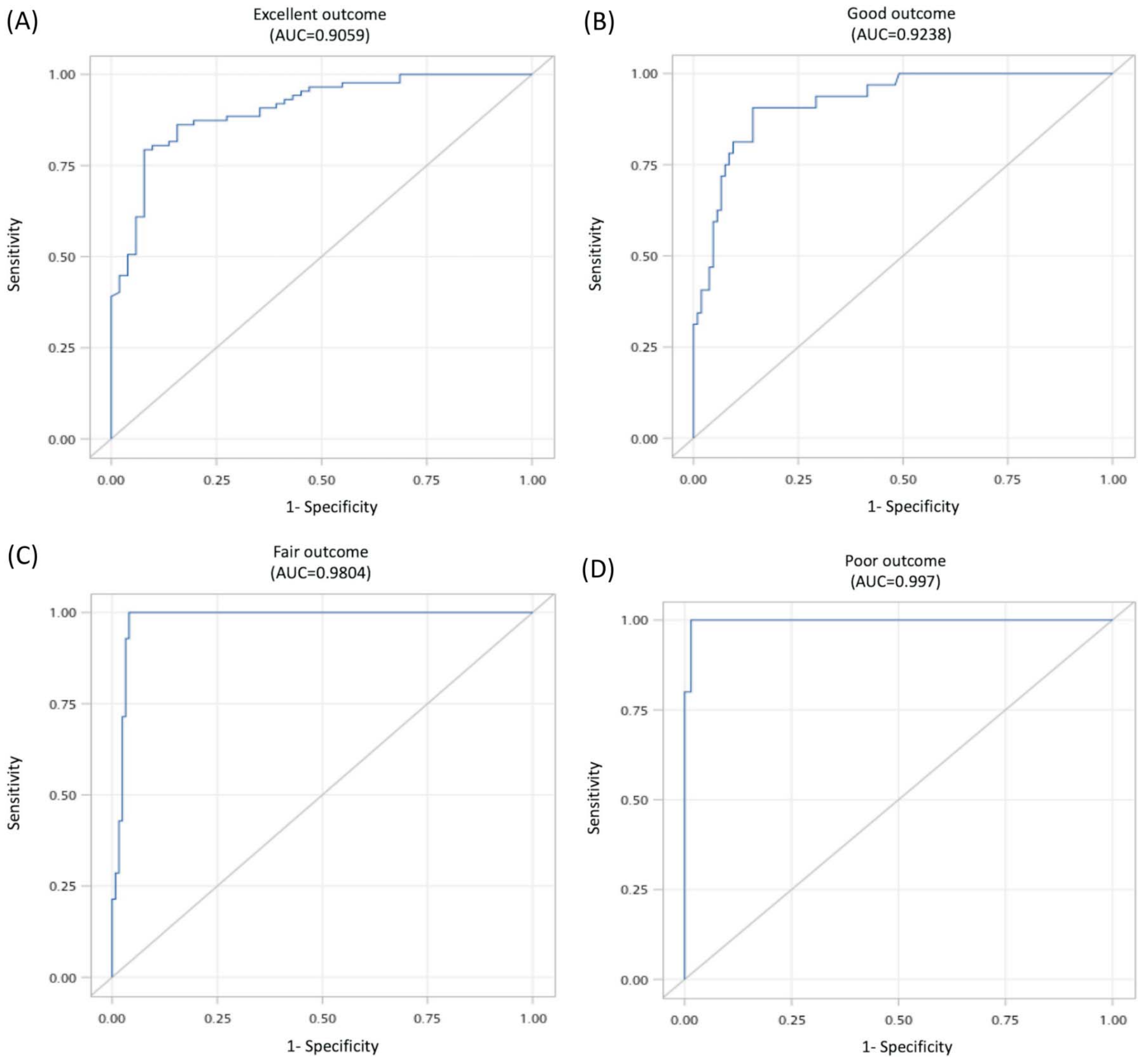

Figure 1. Receiver operating characteristic (ROC) curves for short-term clinical outcomes. (A) Prediction results for excellent outcomes. (B) Prediction results for good outcomes. (C) Prediction results for fair outcomes. (D) Prediction for poor outcomes. AUC, area under the ROC curve.

Table 5
Univariate logistic regression results for patients with excellent or good short-term clinical outcomes.

Factors	Odds ratio	95% confidence interval		p value
Age ≥ 65 years	1.004	0.376	2.676	0.994
Blood loss ≥ 200 ml	0.715	0.269	1.904	0.502
The length of hospital day ≥ 7 days	0.36	0.135	0.963	0.042
Presence of comorbidities	0.659	0.234	1.854	0.43
The changes of VAS ≥ 5 points	2.72	0.998	7.414	0.05
The length of operation time ≥ 240 minutes	0.295	0.108	0.808	0.018
The number of MIS-TLIF ≥ 2 levels	0.522	0.281	0.971	0.04

Table 6
Multivariate logistic regression results for patients with excellent or good short-term clinical outcomes.

Factors	Odds ratio	95% confidence interval		p value
Age ≥ 65 years	1.214	0.405	3.644	0.165
Blood loss ≥ 200 ml	1.411	0.39	5.1	0.6
The length of hospital day ≥ 7 days	0.461	0.156	1.366	0.162
Presence of comorbidities	0.626	0.207	1.898	0.408
The changes of VAS ≥ 5 points	2.621	0.907	7.57	0.075
The length of operation time ≥ 240 minutes	0.339	0.074	1.561	0.165
The number of MIS-TLIF ≥ 2 levels	0.939	0.312	2.826	0.911

tients recovered without any surgical intervention. One patient aged ≥ 65 years had a postoperative spinal epidural hematoma, which required surgical removal. Four patients aged < 65 years had superficial surgical wound infections.

4. Discussion

MIS-TLIF, first reported by Foley et al. in 2002,[14] is the mainstay of treatment for degenerative lumbar disease. The main advantages of MIS-TLIF over midline posterior approaches are greater preservation of posterior structures; reduced approach-related muscle damage, neural retraction injury, epidural fibrosis, and postoperative pain; early ambulation; and decreased length of hospital stay.[9,15] However, the benefit of MIS-TLIF in geriatric patients with lumbar degeneration diseases remains unclear in the literature; this is because of differences in the definition of geriatric populations and limited reporting of risk factors among published studies.[1,10]

The two main factors affecting surgical risk in geriatric patients undergoing MIS-TLIF, compared with younger patients, are older age and more comorbidities. Our study revealed that patients aged ≥ 65 years who underwent MIS-TLIF had more comorbidities than did the younger patients. Nevertheless, several studies have reported that operation duration, anesthesia time, estimated blood loss, and postoperative length of hospital stay did not differ significantly between older patients and younger patients.[16–18] Another study revealed that compared with younger age (< 65 years), older age (> 75 years) was associated with a longer length of hospital stay and longer time to ambulation.[19] Length of hospital stay was also previously reported to be significantly longer in older patients than in younger patients, especially when more than one MIS-TLIF level was administered.[20] The present study revealed that the patients aged ≥ 65 years had more comorbidities than did those aged < 65 years. However, only the rate of hypertension was significantly higher in the patients aged ≥ 65 years (60% vs. 39.7%, $p = 0.012$). Furthermore, our study showed that 63.8% of the patients aged ≥ 65 years underwent ≥ 2-level MIS-TLIF, whereas 63.8% of the patients age < 65 years underwent 1-level MIS-TLIF. According to these findings, degenerative lumbar diseases seem to be more complicated in older patients, necessitating more surgical interventions in such patients. Our study demonstrated that higher MIS-TLIF levels were associated with a longer operation duration, more intraoperative blood loss, and a longer length of hospital stay. We observed that regardless of MIS-TLIF levels, the patients aged ≥ 65 years had a higher level of intraoperative blood loss. However, our subgroup analysis based on MIS-TLIF levels indicated that the differences in the aforementioned factors between the patients aged ≥ 65 years and those aged < 65 years were not significant.

Clinical outcomes such as pain or quality-of-life improvements are crucial in geriatric patients receiving MIS-TLIF.[10] Increasing bodies of evidence demonstrate similar improvements in back pain, leg pain, ODI, and SF-36 in elderly patients aged ≥ 65 years.[16,21] A previous study revealed that of younger and older patients, 85% and 85% were satisfied with their clinical outcomes, respectively, and that 87% and 80% had their expectations fulfilled, respectively.[21] In our study, a higher proportion of the patients aged ≥ 65 years had poor outcomes compared with those aged < 65 years (5% vs. 1.7%, $p = 0.309$). However, 86.3% of the patients aged ≥ 65 years had favorable outcomes, which was comparable to that of those aged < 65 years (86.2%) ($p = 0.994$).

To determine factors contributing to short-term clinical outcomes, we conducted a regression analysis using the following factors: age ≥ 65 years, intraoperative blood loss ≥ 200 mL, length of hospital stay ≥ 7 days, presence of comorbidities, postoperative changes in VAS scores ≥ 5 points, operation duration ≥ 240 minutes, and the number of MIS-TLIF ≥ 2 levels. Our decision tree-based prediction model revealed that the AUC for each outcome was > 0.9. Accordingly, this model was determined to achieve a high accuracy in distinguishing short-term clinical outcomes in patients who underwent MIS-TLIF. Our univariate analysis showed that length of hospital stay ≥ 7 days (OR = 0.36), operation duration ≥ 240 minutes (OR = 0.295), and the number of MIS-TLIF ≥ 2 levels (OR = 0.522) were negatively associated with favorable clinical outcomes. However, our multivariate analysis showed no significant correlation. Accordingly, our findings demonstrate the effectiveness of MIS-TLIF in geriatric patients with degenerative lumbar diseases and that MIS-TLIF could achieve similar outcomes in geriatric patients and patients aged > 65 years.

Length of hospital stay, comorbidities, and operation duration were determined to be predictive of major and minor complications in patients who underwent multiple MIS-TLIF levels.[22] However, studies have reported that geriatric patients who underwent multiple MIS-TLIF levels had comparable overall, major, or minor complication rates.[17,19,22,23] A meta-analysis revealed that the OR for approach-related complication rates in older patients was 1.59 (95% CI: 0.59–4.27), which did not differ significantly from that observed in younger patients.[10] However, a study noted that age was not a predictor of complications.[22] Other studies have indicated that the rates of approach-related complications such as wound healing disorders, hematomas, screw malposition, and cerebrospinal fluid leakage were 5.3%–7.5%.[20,24] In addition, research has revealed that older age was not associated with postoperative complications.[20,24] In our study, incidental durotomy with cerebrospinal fluid leakage was present in three patients aged ≥ 65 years and two patients aged < 65 years. Only one patient aged ≥ 65 years had postoperative spinal epidural hematoma. However, 63.8% of the patients aged ≥ 65 years underwent ≥ 2-level MIS-TLIF. Our findings demonstrate that approach-related complications were present in only approximately 5% of the patients aged ≥ 65 years, consistent with the findings of previous studies.[20,24] Accordingly, our results support the safety of MIS-TLIF, even that involving multiple levels, in geriatric patients.

Our study has several limitations. First, this was a retrospective study with a relatively short follow-up period. Second, we did not include data on bone mineral density testing, which could help examine the association between screw loosening/cage subsidence and bone quality. Additional studies are necessary to investigate the long-term outcomes of MIS-TLIF in geriatric patients.

5. Conclusion

Spinal fusion in geriatric patients is a growing problem in the aged society. This study developed a decision tree-based prediction model for estimating short-term clinical outcomes, and the model was noted to exhibit excellent accuracy. Our study revealed that more than 86% of patients who underwent MIS-TLIF had excellent or good short-term clinical outcomes. Length of hospital stay ≥ 7 days, operation duration ≥ 240 minutes, and MIS-TLIF level were suggested to be negative factors for favorable clinical outcomes. However, patients aged ≥ 65 years had similar favorable short-term clinical outcomes to those aged < 65 years. Our results demonstrate the positive value of MIS-TLIF in geriatric patients with degenerative spinal diseases.

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Conflicts of interest

We declare that there are no conflicts of interest relevant to this study.

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