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Computer-assisted Minimally Invasive Transforaminal Lumbar Interbody Fusion May Be Better Than Open Surgery for Treating Degenerative Lumbar Disease

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Study Design: This study was a retrospective review of prospectively collected clinical data.

Objective: To evaluate the clinical and radiologic outcomes of computer-assisted minimally invasive spine surgery transforaminal lumbar interbody fusion (CAMISS-TLIF) and open TLIF for the treatment of 1-level degenerative lumbar disease.

Summary of Background Data: Minimally invasive TLIF is becoming increasingly popular; however, the limited space and high rate of hardware complications associated with this method are challenging to surgeons. Computer-assisted navigation has the potential to dynamically show the fine anatomic structures, which could theoretically facilitate minimally invasive spine procedures.

Methods: Sixty-one patients underwent 1-level TLIF procedures (30, CAMISS-TLIF; 31, open TLIF). The computer-assisted navigation system was used for CAMISS-TLIF, whereas conventional fluoroscopy was used for open TLIF. Demographic, operative, visual analog scale, and Oswestry disability index data were collected. Screw insertion was assessed by computed tomography, and radiologic fusion based on Bridwell grading was evaluated 2 years after surgery by independent investigators.

Results: The CAMISS-TLIF group had significantly less blood loss, postoperative drain, need for transfusion, and initial postoperative back pain; earlier rehabilitation; and shorter postoperative hospitalization than the open TLIF group, whereas CAMISS-TLIF took longer surgical time than open TLIF. However, no significant differences between the 2 groups in visual analog scale scores and Oswestry disability index were observed at 3 months, 1 year, and 2 years postoperatively. A total of 93.33% and 73.39% of screws in the CAMISS and open groups, respectively, had no pedicle perforation ($P = 0.016$), and the fusion rate was similar in both groups ($P = 0.787$).

Conclusions: Computer-assisted navigation facilitated minimally invasive spine surgery-TLIF. CAMISS-TLIF was superior to open TLIF for treating 1-level degenerative lumbar disease, although it required longer operation time in the initial stage. CAMISS-TLIF showed several benefits compared with open TLIF, including less intraoperative blood loss, postoperative drainage, and pain; earlier rehabilitation; and shorter postoperative hospitalization.

Key Words: computer-assisted minimally invasive spine surgery, transforaminal lumbar interbody fusion, degenerative lumbar disease, open approach, pedicle screws

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The limited visualization and steep learning curves associated with minimally invasive spine surgery transforaminal lumbar interbody fusion (MISS-TLIF), commonly result in hardware-associated complications[1] and incomplete neural decompression,[2] thus compromising the efficacy and safety of the procedure. We have previously demonstrated the safety and accuracy of computer-assisted pedicle screw placements of the upper cervical[3] and lumbar vertebrae with axial rotation,[4] and on the basis of these results, we combined the advantages of computer-assisted navigation and minimally invasive spine surgery. We called this novel method computer-assisted minimally invasive spine surgery (CAMISS) and have previously successfully used this technique to treat thoracolumbar fractures, with benefits including less bleeding and faster recovery.[5] However, to date, no study in the literature has compared the outcomes of CAMISS-TLIF with those of open TLIF. In this study, we aimed to compare the clinical and radiographic outcomes of CAMISS-TLIF with those of open TLIF and to determine the appropriate treatment for degenerative lumbar disease.

PATIENTS AND METHODS

Patients

Utilizing specific inclusion and exclusion criteria (Table 1), and following IRB approval (Beijing Jishuitan

TABLE 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Symptomatic degenerative disease of the lumbosacral spine (L2 to S1)	Age < 18 y or > 65 y
No response to nonoperative treatments for 6 mo	Previous lumbar surgery
Single-level involvement	Osteoporosis
	Spinal trauma or infections

Hospital), 61 patients were selected to undergo either CAMISS-TLIF (30 patients) or open TLIF (31 patients) between May 2010 and December 2011, and were followed for 3, 6, 12, and 24 postoperative months.

Clinical Evaluations

The prospective analyses of preoperative, perioperative, and postoperative parameters included factors such as patient age, sex, weight, height, preoperative diagnosis, operated level, operating time, intraoperative blood loss, postoperative drain, days with drain, total amounts of transfusion, pain scores, time before ambulation, postoperative hospital stay, and complications. The visual analog scale (VAS) was used to evaluate preoperative and postoperative pain of the back and legs. The Oswestry disability index (ODI) version 2.0 was used to evaluate the patients' daily life functions.

Surgical Techniques

CAMISS-TLIF

Each patient received general anesthesia and was positioned prone on a radiolucent Jackson table. The computer-assisted navigation system consisted of a modified C-arm computed tomography (CT) system (Arcadis Orbic 3D; Siemens Medical Solutions, Erlangen, Germany), a navigation workstation (Stryker Spine Navigation System, version 1.2, Missouri, MO), and specific instruments (patient tracker, pointer, pedicle awl, and pedicle probe) equipped with light-emitting diodes. Using fluoroscopy, the targeted segment was located. A reference array was fixed on a spinous process and cephalad to the targeted segment through a separate incision. The CT-type image data were obtained and transferred to the computer navigation workstation, where they were registered automatically. Using the navigation pointer, the skin incision was planned (Fig. 1). The pedicle screw pilot holes were created using a navigated awl, and K-wires were inserted into pilot holes on both sides. Fusion procedures were performed on the side of the worst radiculopathy, through tubular retractors, as previously described.[6] During the decompression, the navigation pointer was used to display the anatomic structures to ensure sufficient decompression.

Open TLIF

Using a midline skin incision, conventional TLIF was performed as previously described.[7]

In both groups, bilateral pedicle screw-rod constructs were used, each wound was irrigated, and a vacuum drainage was placed on the symptomatic side before wound closing. The tube was removed when the drainage was reduced to < 50 mL in a 24-hour period.

Radiologic Evaluations

Immediate postoperative CT scans were assessed for screw positions, and the screws were graded according to a validated standardized scale[8] (Table 2). Radiographs (anteroposterior and lateral images) were used to affirm the fusion rates annually after the operation, and CT scans were adopted, if necessary. The Bridwell interbody fusion grading system (Table 2) was used to evaluate the fusion status. Grades I and II were considered solid fusions. To reduce bias, independent investigators performed the data collection and analyses.

Statistical Analysis

Statistical analyses were performed with SPSS version 17.0 (SPSS Inc., Chicago, IL). The Student t test was used to compare continuous variables, the Kolmogorov-Smirnov Z test was used to compare nonparametric continuous variables, and χ^2 or Fisher exact tests were used to evaluate differences in categorical variables between the 2 groups. For all analyses, a P value < 0.05 was considered significant.

RESULTS

The mean follow-up was 25.63 months (range, 24–31 mo). No significant differences in age, sex ratio, body mass index, preoperative diagnoses, and levels of surgery were observed between the 2 groups. No cases of CAMISS-TLIF were converted to open surgery (Table 3). CAMISS-TLIF required longer surgical time than open TLIF (median times, 155.00 and 115.00 min, respectively; $P < 0.001$). The CAMISS-TLIF group showed significantly less intraoperative blood loss and postoperative drainage than the open group ($P < 0.001$ for both), and the drain was required for fewer days in the CAMISS-TLIF group ($P < 0.001$). None of the patients in the CAMISS-TLIF group required transfusions, whereas 5 (16.13%) patients in the open group required perioperative blood transfusions (2 U of red blood cells). Moreover, patients in the CAMISS-TLIF group could ambulate earlier and required a shorter postoperative stay than patients in the open group ($P < 0.001$ for both) (Table 4).

On the basis of the VAS, postoperative back pain was significantly reduced in the CAMISS-TLIF group on days 3, 7, and 14 postsurgery compared with that in the open group. However, no differences in postoperative pain were noted after this time. No significant differences in the VAS scores for leg pain or in the ODI were observed between the 2 groups (Table 5).

In all, 93.33% (112/120) of the pedicle screws in the CAMISS-TLIF group were accurately placed (grade 0) compared with 73.39% (91/124) in the open TLIF group (Fig. 2). There were 8 (6.67%) and 26 (20.97%) grade 1

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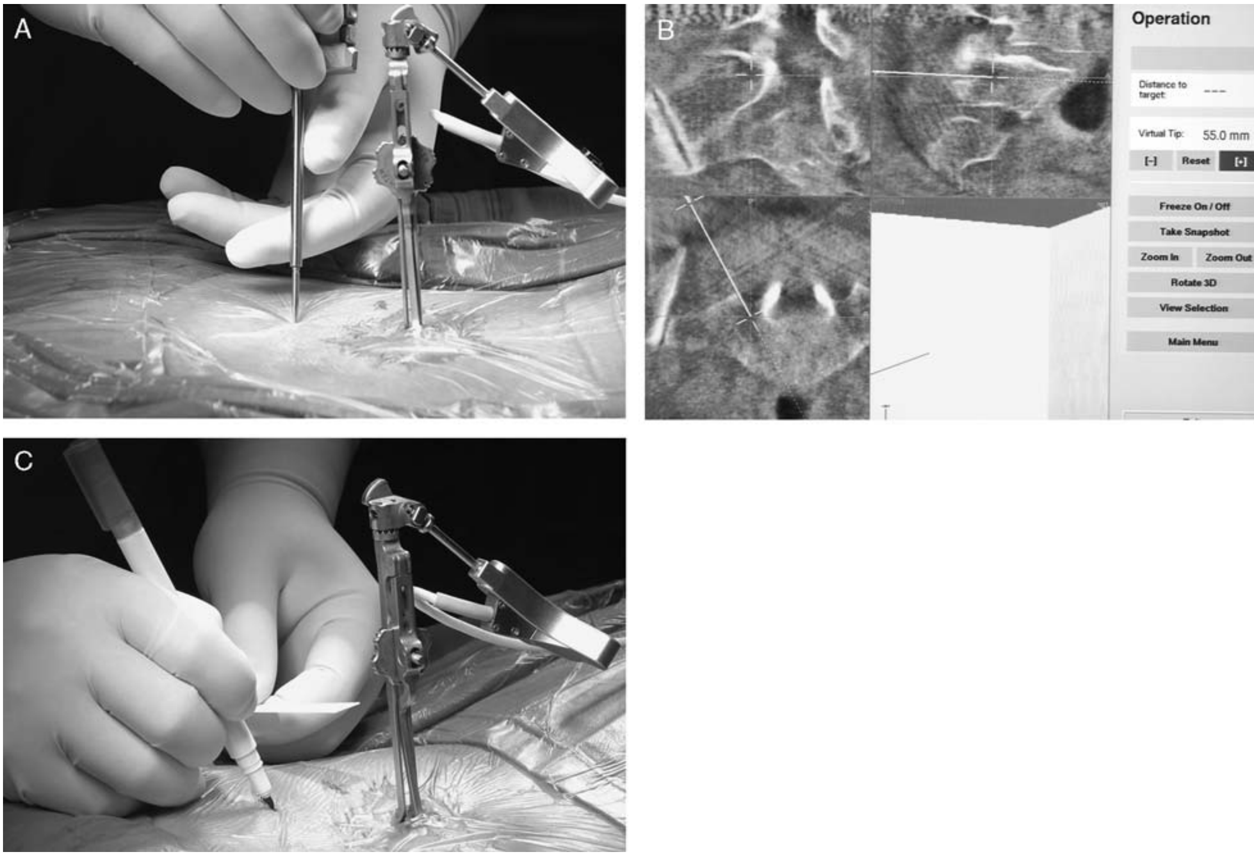

FIGURE 1. A, A navigation pointer was used to design the skin incision. B, By viewing the navigation screen, the shortest and safest approach could be determined. C, Marking of a satisfactory incision on the skin.

screw insertions for the CAMISS-TLIF and open TLIF groups, respectively. Seven (5.64%) grade 2 and no grade 3 screw insertions were observed in the open group; in comparison, no grade 2 or 3 screws were noted in the CAMISS-TLIF group ($P = 0.016$). No significant differences in the fusion rate were observed between the 2 groups 2 years after surgery ($P = 0.738$), with solid fusion being achieved in 29 (96.67%) and 29 (93.55%) patients in the CAMISS-TLIF and open groups, respectively (Fig. 3; Table 4).

TABLE 2. Pedicle Screws Accuracy Grading and Interbody Fusion Grading

Pedicle Screw Position Assessment	Bridwell Interbody Fusion Grading System
Grade 0: no pedicle perforation	Grade I: fused with remodeling and trabeculae present
Grade 1: < 2 mm of the screw threads located outside the pedicle	Grade II: graft intact, not fully remodeled and incorporated, but no lucency present
Grade 2: 2–4 mm of the core screw located outside the pedicle	Grade III: graft intact, potential lucency present at the top and bottom of the graft
Grade 3: entire screw located outside the pedicle	Grade IV: fusion absent with collapse/resorption of the graft

In the CAMISS-TLIF group, 1 (3.33%) patient developed right L5 root palsy because of a local hematoma, for which she underwent emergency operation (the patient recovered completely in 3 mo), and 1 (3.33%) patient developed transient radicular pain. In the open TLIF group, 2 (6.45%) patients developed wound infection. One patient with superficial wound infection underwent wound dressing, and the other patient with deep wound infection was given debridement and antibiotic treatment. No cases of instrumentation failure were observed.

DISCUSSION

In the present study, we combined CAMISS with TLIF as a novel method to treat degenerative lumbar disease and compared its effectiveness with open TLIF. We found that the accuracy of pedicle screw placement was 93.33% and 73.39% for CAMISS-TLIF and open TLIF, respectively ($P = 0.016$). The superior results obtained by CAMISS-TLIF were due to the fact that CAMISS-TLIF allows clear visualization of the 3-dimensional spinal anatomy, which enables the surgeon to choose the optimal entry point and trajectory for pedicle screw placement. Moreover, the surgeons can use the

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TABLE 3. Baseline Demographic Characteristics and Preoperative Factors of the Study Patients (n = 61)

Variable	CAMISS-TLIF Group (n = 30)	Open TLIF Group (n = 31)	*P*
Mean age (y)	48.21 ± 9.10	48.90 ± 8.89	0.953
Sex (female/male)	14/16	8/23	0.114
Mean BMI (kg/m^2)	24.92 ± 2.76	26.18 ± 3.77	0.146
Spinal level fused [n (%)]			0.767
L3-4	2 (6.7)	1 (3.2)	
L4-5	14 (46.7)	17 (54.8)	
L5-S1	14 (46.7)	13 (41.9)	
Diagnosis [n (%)]			0.642
Symptomatic lumbar stenosis	3 (10.0)	4 (12.9)	
Symptomatic lumbar spondylolisthesis	3 (10.0)	6 (19.4)	
Symptomatic lumbar disc herniation	24 (80.0)	21 (67.7)	

BMI indicates body mass index; CAMISS, computer-assisted minimally invasive spine surgery; TLIF, transforaminal lumbar interbody fusion.

TABLE 4. Perioperative Outcomes of Patients who had Undergone CAMISS-TLIF and Open TLIF

Categorical Variable	CAMISS-TLIF Group (n = 30)	Open TLIF Group (n = 31)	*P*
Surgical time (min)	159.20 ± 20.12	113.06 ± 23.19	< 0.001
Intraoperative blood loss (mL)	142.17 ± 72.01	231.29 ± 109.84	< 0.001
Postoperative drainage (mL)	74.83 ± 41.91	376.29 ± 154.13	< 0.001
Days with drainage	2.07 ± 0.64	3.19 ± 0.75	< 0.001
Days before ambulation	1.57 ± 0.90	2.58 ± 0.72	< 0.001
Postoperative stay (d)	4.53 ± 1.50	5.58 ± 0.79	0.001
Bridwell grade of fusion [n (%)]			0.787
I	26 (86.7)	25 (80.6)	
II	3 (10.0)	4 (12.9)	
III	1 (3.3)	2 (6.5)	
IV	0 (0)	0 (0)	

CAMISS indicates computer-assisted minimally invasive spine surgery; TLIF, transforaminal lumbar interbody fusion.

TABLE 5. Postoperative Oswestry Disability Index Scores and Visual Analog Scale Scores for Back and Leg Pain of the CAMISS-TLIF and Open TLIF Groups

Categorical Variable	CAMISS-TLIF Group (n = 30)	Open TLIF Group (n = 31)	*P*
Preoperative VAS for back pain	4.86 ± 1.16	4.87 ± 1.29	0.989
Postoperative VAS for back pain			
3 d	3.31 ± 0.56	5.01 ± 0.85	< 0.001
7 d	2.55 ± 0.52	3.48 ± 0.65	< 0.001
2 wk	2.20 ± 0.56	2.50 ± 0.59	0.048
3 mo	2.07 ± 0.56	2.34 ± 0.58	0.071
1 y	1.60 ± 0.50	1.51 ± 0.44	0.455
2 y	1.30 ± 0.34	1.16 ± 0.44	0.147
Preoperative VAS for leg pain	6.35 ± 1.41	6.41 ± 1.32	0.858
Postoperative VAS for leg pain			
3 mo	2.09 ± 0.59	1.95 ± 0.52	0.333
1 y	1.42 ± 0.62	1.41 ± 0.56	0.946
2 y	1.05 ± 0.66	1.07 ± 0.58	0.928
Preoperative ODI (%)	43.56 ± 4.85	44.71 ± 5.42	0.387
Postoperative ODI (%)			
3 mo	24.75 ± 3.74	24.67 ± 3.44	0.514
1 y	20.93 ± 2.67	20.78 ± 2.45	0.115
2 y	17.23 ± 2.83	18.24 ± 2.38	0.348

CAMISS indicates computer-assisted minimally spine invasive surgery; ODI, Oswestry disability index; TLIF, transforaminal lumbar interbody fusion; VAS, visual analog scale.

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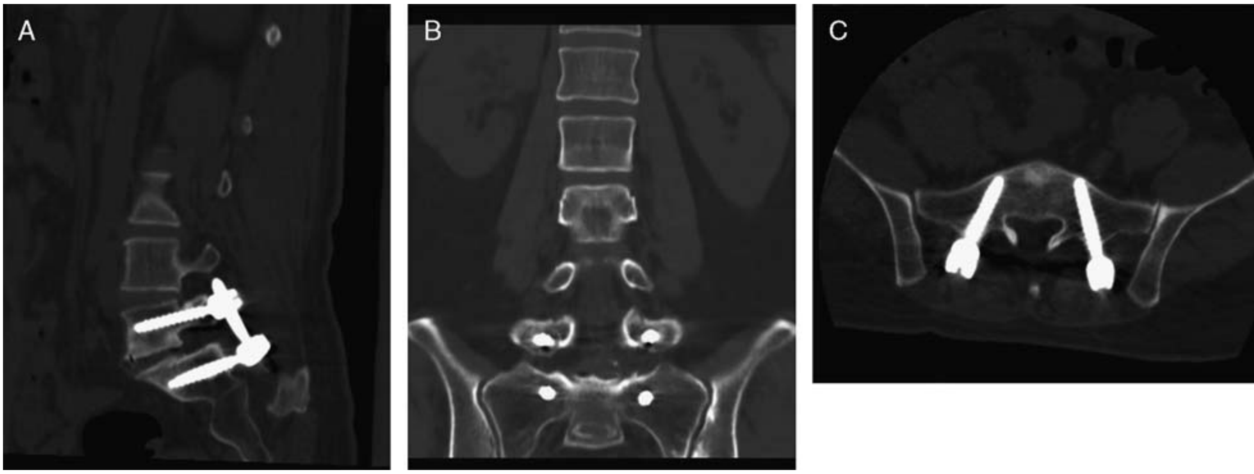

FIGURE 2. Postoperative computed tomography scan showing the accuracy of pedicle screw placement (multiplanar views). Pedicle screw placements in the (A) sagittal plane, (B) coronal plane, and (C) axial plane.

navigation software to choose the optimal diameter and length of the pedicle screws, thereby reducing the rate of screw-related complications. In contrast, traditional fluoroscopy provides 2-dimensional images containing many overlapping important messages, and is relatively difficult to master.[9]

One factor affecting the clinical outcomes in minimally invasive procedures is incomplete decompression, which may limit exposure and visualization, and thus, the region of compression may go undetected and untreated.[2] CAMISS-TLIF facilitates decompression of the bone structure, which is very important to ensure the scope of sufficient bone decompression and to avoid extensive damage to stable structures. In this study, we could identify the bone structure clearly, even in small spaces, by using the pointer and viewing the navigation screen, without discriminating the bone structure through the tubular retractor. If necessary, a postoperative scan could be performed before closing to ensure sufficient decompression and to evaluate the position of the implant.

Both groups showed significant improvement in clinical outcomes at 2 years compared with that preoperatively, and no differences were found between the 2 groups in terms of VAS for leg pain, ODI, and fusion rates, suggesting that effective neurological decompression and bony fusion can be achieved by both CAMISS-TLIF and open surgery. We found that CAMISS-TLIF reduced intraoperative blood loss, and no patients in the CAMISS-TLIF group required transfusions. Moreover, the VAS score for initial postoperative back pain was lower in the CAMISS-TLIF group, with most patients in this group starting rehabilitation earlier, recovering sooner, and having shorter postoperative stays. These results are consistent with those of a previous

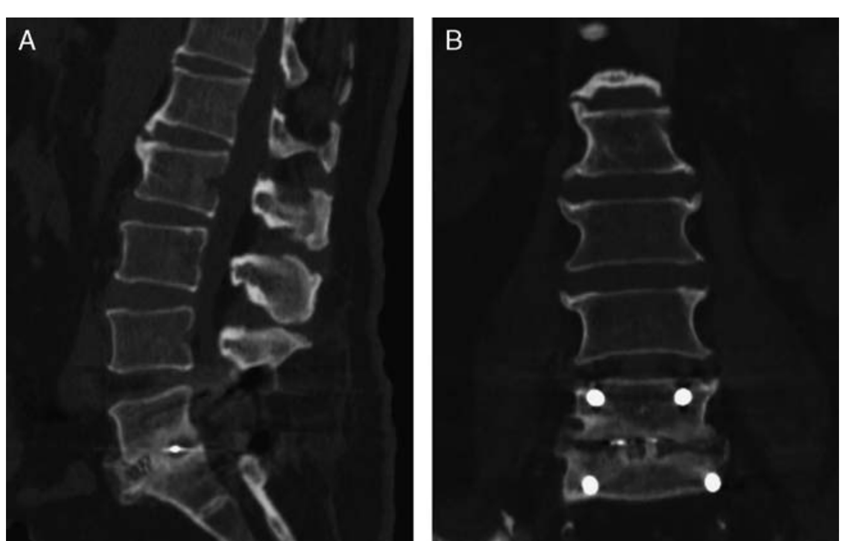

FIGURE 3. Postoperative computed tomography scan 2 years after surgery confirming interbody fusions. A, Sagittal plane. B, Coronal plane.

study,[6] because of minimizing iatrogenic damages to the soft tissue around the spine. In the CAMISS-TLIF group, we used computer-assisted navigation to design the incision and took the short approach to the surgical target; furthermore, only small incisions are required, and the procedure is performed through the muscle anatomic planes. In contrast, open surgery requires a large middle line incision or extensive dissection and high-force retraction of the paraspinal muscles by retractors.

In the CAMISS-TLIF group, 1 case of epidural hematoma occurred, which could have likely been avoided if careful attention had been paid to the epidural veins using bipolar cautery. Another case of transient radiculopathy was noted, and this was probably caused by the aggressively disturbed neural element during the fusion procedure. No patient in the CAMISS-TLIF group developed infections, which is consistent with the results of a previous primary study.[10]

This study has numerous limitations. First, the cases reported here are our initial CAMISS-TLIF cases. Any new technology bears a significant learning curve, and developing skills takes time. After mastering this new technology, the operative time may be the same as, or even shorter than, open TLIF. Second, it was not a randomized-controlled trial, and hence, future randomized-controlled studies are required to confirm our results and to ensure the reliability of the method. Lastly, the number of patients involved in the study was relatively small, and future studies with more participants are warranted.

CONCLUSIONS

In this study, we found that computer-assisted navigation improved the incision design, screw insertion, and decompression in MISS; thus, this technique may allow surgeons to perform complex minimally invasive spine surgeries. CAMISS-TLIF appears to have several measurable clinical benefits, including less intraoperative blood loss, postoperative drainage, and initial postoperative back pain, as well as earlier rehabilitation and shorter postoperative hospitalization than open TLIF. Thus, we conclude that CAMISS-TLIF may be superior to open TLIF in the treatment of 1-level degenerative lumbar disease, although it requires a longer surgical time in the initial stages.

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