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Comparison of Two Extended Interbody Fusion Techniques in the Treatment of Adjacent Segment Disease after Transforaminal Lumbar Interbody Fusion: Using Cortical Bone Trajectory Screws *vs.* Traditional Pedicle Screws Combined with a Novel Domino System

*Xin Song[1], Donglin Ren[1], Shuai Han[1], Desheng Wu[2] and Jian Wang[1]**

[1]Department of Orthopedics, Pudong New District Peoples' Hospital, Shanghai, China

[2]Department of Spine Surgery, Shanghai East Hospital affiliated to Tongji University, Shanghai, China

Abstract

Objective: To illustrate two minimally invasive extended interbody fusion techniques using Cortical Bone Trajectory screws with Posterior Lumbar Interbody Fusion (CBT-PLIF) and Traditional Pedicle Screws and a Domino System with Transforaminal Lumbar Interbody Fusion (TPS-Domino-TLIF) for Adjacent Segment Disease (ASD) after lumbar fusion surgery, and compare the postoperative radiographic and clinical outcomes between the both techniques for ASD.

Methods: A retrospective study including 72 patients was conducted in this study, 32 patients received CBT-PLIF and the other 40 patients received TPS-Domino-TLIF. Patient demographics, surgical data, complications, radiologic and clinical outcomes were evaluated and compared between the two groups.

Results: There was significantly shorter surgical duration, as well as less Estimated Blood Loss (EBL) and a lower frequency of intra-operative fluoroscopy, in TPS-Domino-TLIF when compared with CBT-PLIF ($p<0.05$). The lumbar lordotic angle was improved both at immediate post-operation ($p=0.006$) and the last follow-up ($p=0.007$) in TPS-Domino-TLIF group as compared with CBT-PLIF group. The larger mean inter-vertebral height in TPS-Domino-TLIF group was observed than that in CBT-PLIF group at immediate post-operation ($p=0.007$) and the last follow-up ($p=0.005$). The clinical outcomes containing the mean VAS-back, VAS-leg and ODI were improved significantly postoperatively in both groups.

Conclusion: Advantaged by shorter surgical duration, less Estimated Blood Loss (EBL), a lower frequency of intra-operative fluoroscopy, and superior radiological outcomes, TPS-Domino-TLIF could be considered a viable alternative to the midline fusion technique using CBT for ASD.

Keywords: ASD; Lumbar fusion; Traditional pedicle screws; CBT

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***Correspondence:**
Jian Wang, Department of Orthopedics, Pudong New District Peoples' Hospital, South Chuanhuan Road No. 490, Pudong New District, Shanghai, 201299, China,
E-mail: pryspine@126.com

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Introduction

Adjacent Segment Disease (ASD), especially Symptomatic Adjacent Segment Disease (S-ASD), has increasingly become a common concern in patients undergoing spinal fusion surgery [1-12]. Abnormal biomechanical stress at the adjacent level or natural history in elderly people is reckoned to contribute to the occurrence of ASD. A large number of research has unveiled that the prevalence of radiographic ASD approximates up to 84% and that of symptomatic ASD ranges from 5.2% to 31% [2,3,6,11]. Usually, simple radiographic ASD may not need radical treatment. Only patients, who present neurogenic claudication, lower extremity radiculopathy, or both, which is defined as S-ASD, require standard conservative treatment. Patients who fail to respond to conservative treatment eventually need to be tackled with conventional surgical techniques, including removal of the existing rod at the index surgical level, fusion extension using PS, and rod-screw assembly at the expense of wider dissection, greater blood loss and a longer operative duration. It is therefore necessary to seek an optimal minimal invasive surgery technique for the treatment of ASD.

As a minimally invasive surgery technique, Percutaneous Endoscopic Lumbar Discectomy (PELD) has been gaining favor, but extremely rigorous indications limit its application for ASD in patients with spinal stenosis or instability. As yet, spinal fusion still plays a pivotal role in surgery for S-ASD.

The Cortical Bone Trajectory (CBT) screw technique, initially introduced by Santoni et al. in 2009, possesses comparable biomechanical characteristics to the Traditional Pedicle Screws (TPS) technique [13-18]. In recent years, the midline fusion technique with CBT screws has been developed and offered excellent clinical outcomes [19]. However, few studies about the midline fusion technique for S-ASD have been reported in the literature. Furthermore, the optimal CBT screws implantation is difficult to achieve due to the preexisting screws at the index level. So, a novel Domino system combined with the TPS technique, extensively used in scoliosis correction surgery, was applied for the extended spinal fusion surgery of S-ASD in our institution.

Herein, we present a retrospective cohort study aiming to compare the radiographic and clinical outcomes between patients who underwent CBT screw fixation and Posterior Lumbar Interbody Fusion (CBT-PLIF) and those who underwent transforaminal lumbar interbody fusion combined with a novel Domino system (TPS-Domino-TLIF) for the sake of screening an optimal approach in the treatment of S-ASD.

Methods

Patient selection

With approval from the institutional review board of the hospital, a retrospective cohort study was conducted including 72 patients who underwent a single-level CBT-PLIF or TPS-Domino-TLIF in S-ASD at a single academic institution from 2011 to 2018. All patients were followed up for at least 24 months. The mean age at the time of surgery was 68.3 (58 to 78) years. The level of ASD was cranial in all cases. Surgical indications consisted of neurological compromise, intermittent claudication, and/or intractable lower extremity radiculopathy with or without low-back pain after standard conservative treatment including a combination of anti-inflammatory medications, activity modification, and/or injection therapies.

Surgical techniques

All procedures were accomplished by a single senior spine surgeon. Thirty two cases were involved in CBT-PLIF group and 40 cases in TPS-Domino-TLIF group.

CBT-PLIF group (Figures 1A-1F): Under general anesthesia, the lamina of the surgical segment was exposed *via* spinous process splitting guided by original surgical incision. The lower inner margin of the superior articular process was defined as the entry point of CBT, whose trajectory followed a lateral angle of 8 to 9 degrees and a cephalad angle of 25 to 26 degrees with slight modification based on the preexisting pedicle screw position at the index level. Then, the PLIF procedures were carried out routinely.

TPS-Domino-TLIF group (Figures 2A-2F): Unlike CBT-PLIF group, the exposure in TPS-TLIF group was more laterally including the proximal end of the original rods. Traditional pedicle screws implantation was accomplished only at the proximal level with the index level preexisting pedicle screws remaining. Next, the procedures of TLIF were conducted regularly. Finally, two extra rods were linked and tightened firmly to the original rods bilateral using a novel Domino system (Bai Xin Medical Devices Company, Shanghai, China) (Figure 3).

All screw implantation procedures were monitored and verified by intra-operative fluoroscopy. The autograft bone fusion was applied in each patient. After confirming that the wound had healed without infection, discharge was scheduled and the patients were followed up regularly. All patients were advised to wear the canvas corset for six weeks post-operation.

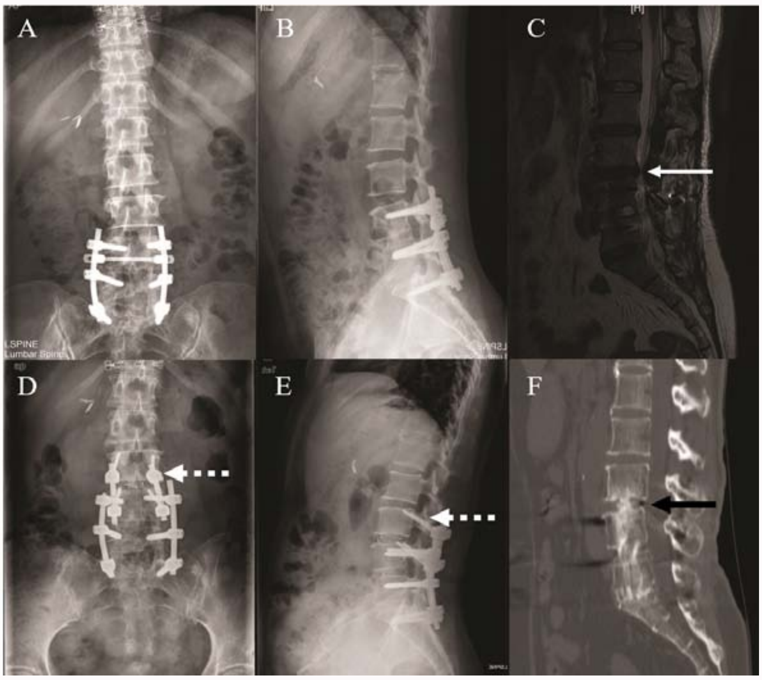

Figure 1: A patient aged 66 years underwent extended fusion surgery using CBT screws and PLIF. A-B: preoperative lumbar AP X-ray lateral X-ray. C: Preoperative MRI shows lumbar spinal stenosis at the level of L3-4 (white arrow). D-E: Postoperative lumbar AP X-ray lateral X-ray (the white dashed arrow illustrates CBT screw fixation). F: CT findings confirm bone fusion at the operation level (black arrow).

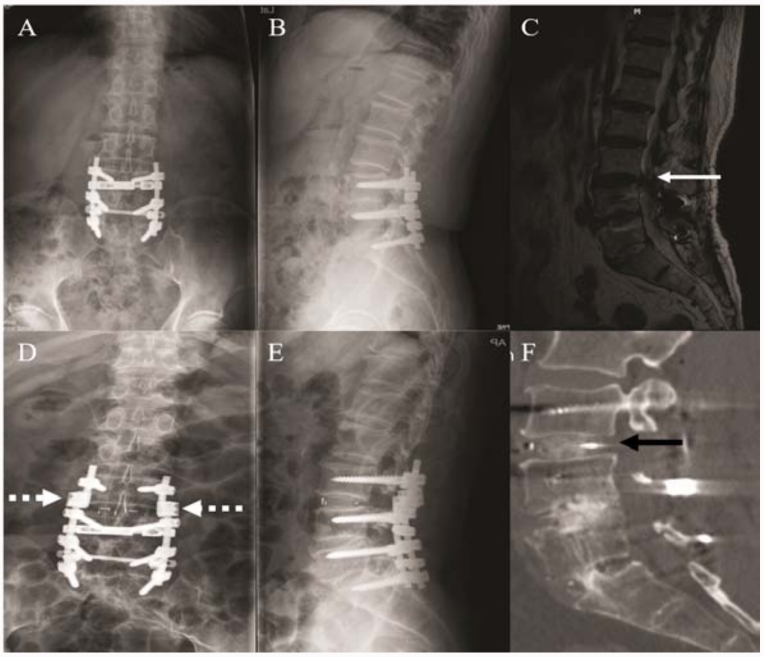

Figure 2: A patient aged 69 years underwent extended fusion surgery using TPS, Domino, and PLIF. A-B: preoperative lumbar AP X-ray lateral X-ray. C: Preoperative MRI shows lumbar spinal stenosis at the level of L3-4 (white arrow). D-E: Postoperative lumbar AP X-ray lateral X-ray (the white dashed arrow illustrates Domino system implantation). F: CT findings confirm bone fusion at the operated level (black arrow).

Radiographic and clinical data

The demographic variables including age, sex, and Body Mass Index (BMI) and the Smoking Status (SS) were recorded from all patients. Surgical variables, including the date of the initial and revision surgeries, operative duration, Estimated Blood Loss (EBL) and cage size, were also collected.

Patient-Reported Outcomes (PROs) were acquired from all patients preoperatively and postoperatively at 1-day, 2-week, 3-mon and 1-year intervals, and at the most recent postoperative visit using the Visual Analog Scale (VAS) -Back, VAS-Leg surveys and Oswestry Disability Index (ODI).

Preoperative radiographs were evaluated for the presence of pathologies associated with adjacent segment degeneration. Radiologic evaluation was performed by a clinical spine surgeon who was not involved in any of the surgical procedures. Lumbar Lordosis (LL) was measured on preoperative, immediate postoperative (day 1 after surgery), and most recent postoperative radiographs. Intervertebral disc height (the mean value between the anterior and posterior measurements of the distance between the inferior endplate of the cephalad vertebral body and the endplate of the caudal vertebral body). Bone fusion was convinced present when CT imaging demonstrated bony trabeculation across the fused levels and the absence of bony lucencies through the implants.

Statistical analysis

Statistical analysis was performed using SPSS 19.0. Differences in demographic data and operative characteristics between groups were evaluated using independent t tests for continuous variables and χ^2 analysis or Fisher exact test for categorical variable. Postoperative changes in radiographic and clinical variables from preoperative values were analyzed for each group using paired t tests. Radiographic and clinical outcomes were compared between groups using independent t tests. Fusion rates were compared between groups using Fisher exact test. Two-sided P value <0.05 was considered to indicate statistical significance.

Figure 3: A novel Domino system. A: The rod of original surgery. B: A novel Domino system used as a block connecting the original rod to the new rod. C: The new rod of extended fusion surgery.

Results

Perioperative information

The symptoms were relieved remarkably after surgery in all patients. Demographic data, surgical duration, EBL, frequency of intra-operative fluoroscopy, radiological data, and clinical outcomes are demonstrated in Tables 1-4. The surgical duration in TPS-Domino-TLIF group was shorter than that in CBT-PLIF group (p<0.05). EBL and frequency of intra-operative fluoroscopy CBT-PLIF group were higher than those in TPS-Domino-TLIF group (p<0.05). The length of postoperative hospital stay was similar in both groups (p=0.569).

Radiologic outcomes

Imaging data showed that the lumbar lordotic angle was optimized in both groups, but the improvement *vs.* the preoperative lumbar lordotic angle was more pronounced in TPS-Domino-TLIF group both at immediate post-operation (p=0.006) and the last follow-up (p=0.007). The mean inter-vertebral height in TPS-Domino-TLIF group was significantly larger than that in CBT-PLIF group at immediate post-operation (p=0.007) and the last follow-up

Table 1: Demographic data in CBT-PLIF and TPS-Domino-TLIF groups.

Variable	CBT-PLIF Group	TPS-Domino-TLIF Group	p Value
Age at surgery	68.8 ± 5.1	67.9 ± 4.9	0.58
Sex: M/F	18/14	24/16	1
BMI in kg/m^2	29.1 ± 2.9	29.0 ± 2.3	0.868
Smoking: Yes/No	14/18	18/22	1
DM: Yes/No	18/14	22/18	1

Values are expressed as the mean ± standard deviation or as number, unless indicated otherwise.
BMI: Body Mass Index; DM: Diabetes Mellitus
P Values calculated using χ^2 analysis or Fisher exact test (categorical variables) and independent t tests (continuous variables).

Table 2: Operative characteristics.

Variable	CBT-PLIF Group	TPS-Domino-TLIF Group	p Value
OD (min)	131.5 ± 19.8	104.1 ± 16.4	<0.001*
EBL (ml)	209.4 ± 33.0	165.5 ± 30.0	<0.001*
FIOF (times)	7.3 ± 0.9	4.3 ± 0.9	<0.001*
LOS (days)	11.8 ± 2.0	11.4 ± 1.7	0.569

Values are expressed as the mean ± standard deviation
OD: Operation Duration; EBL: Estimated Blood Loss; LOS: Length of Stay; FIOF: Frequencies of Intra-Operative Fluoroscopy
Boldface with asterisk indicates statistical significance. p Values calculated using independent t tests (continuous variables)

(p=0.005), knowing that there was no significant difference between the two groups preoperatively (p=0.851). CT scan showed that the bone fusion rate was 87.5% in CBT-PLIF group and 90% in TPS-Domino-TLIF group.

Clinical outcomes

The mean VAS-back, VAS-leg and ODI in CBT-PLIF group were significant improved from preoperative (5.3 ± 0.8), (6.3 ± 0.9) and (75.3 ± 7.7) to postoperative (2.2 ± 0.4), (1.8 ± 0.4) and (17.3 ± 3.4) (all, P<0.05) *vs.* (5.5 ± 0.8), (6.4 ± 0.8) and (70.0 ± 6.5) to (2.0 ± 0.4), (1.5 ± 0.5) and (18.1 ± 3.4) (all, P<0.05) in TPS- Domino-TLIF group at the last follow-up.

Intraoperative and postoperative complications

Dural tear but no infection occurred in one case in CBT-PLIF postoperatively. One screw-rod failure and one postoperative incision infection developed in the CBT-PLIF group. Screw failure was treated conservatively due to the absence of clinical symptom, and postoperative infection that was treated by debridement operation. All three complicated patients showed favorable outcomes at the most recent follow-up. One case of screw loosening and one postoperative infection were found in the TPS-Domino-TLIF group and managed conservatively. The patient remained clinical silent at the most recent follow-up. There were no cases developing the deterioration of neurological function in the both groups.

Discussion

S-ASD has been found more frequent than used to be after spinal fusion so that clinicians should be concern about the potential probability of ASD occurrence in patients who need to undergo lumbar spinal fusion preoperatively.

Risk factors of ASD after spinal fusion have been evaluated extensively but the reported results are not consistent. Zhong et al. [1] analyzed risk factors of ASD after lumbar fusion in terms of adult lumbar spondylolisthesis and found that simultaneous decompression and preexisting spinal stenosis at the unfused adjacent level were

Table 3: Radiographic outcomes.

Variable	CBT-PLIF Group	TPS-Domino-TLIF Group	p Value
LL(°)			
Preoperative	40.6 ± 7.4	39.2 ± 10.1	0.638
Immediate postoperative	49.0 ± 7.4	52.4 ± 7.9	0.196
Immediate postoperative	21.5 ± 7.5	39.0 ± 22.9	**0.006***
Improvement rate (%)			
Final	47.0 ± 6.6	50.6 ± 7.5	0.141
Final improvement rate (%)	16.9 ± 8.5	34.3 ± 22.9	**0.007***
DH (mm)			
Preoperative	8.7 ± 1.4	8.6 ± 1.6	0.851
Immediate postoperative	10.8 ± 1.4	12.0 ± 1.1	**0.007***
Immediate postoperative	24.7 ± 8.6	44.2 ± 32.2	**0.025***
Improvement rate (%)			
Final	10.4 ± 1.4	11.5 ± 0.9	**0.005***
Final improvement rate (%)	20.3 ± 8.2	38.7 ± 31.3	**0.028***
FR at the last follow-up (%)	87.5	90	1

Values are expressed as the mean ± standard deviation.
LL: Lumbar Lodorsis; DH: Disc Height; FR: Fusion Rate
Immediate postoperative improvement rate = Value (Immediate postoperative-Preoperative)/Value (Preoperative)
Final improvement rate = Value (Final- Preoperative)/Value (Preoperative)
Boldface with asterisk indicates statistical significance. p Values calculated using χ^2 analysis or Fisher exact test (categorical variables) and independent t tests (continuous variables)

Table 4: Clinical outcomes.

Variable	CBT-PLIF Group	TPS-Domino-TLIF Group	p Value
VAS-back			
Preoperative	5.3 ± 0.8	5.5 ± 0.8	0.617
Immediate postoperative	3.0 ± 0.5	2.8 ± 0.6	0.213
Final	2.2 ± 0.4	2.0 ± 0.4	0.084
VAS-leg			
Preoperative	6.3 ± 0.9	6.4 ± 0.8	0.759
Immediate postoperative	2.4 ± 0.5	2.2 ± 0.6	0.224
Final	1.8 ± 0.4	1.5 ± 0.5	0.134
ODI			
Preoperative	75.3 ± 7.7	70.0 ± 6.5	**0.030***
Immediate postoperative	23.6 ± 2.8	20.9 ± 4.4	**0.035***
Final	17.3 ± 3.4	18.1 ± 3.4	0.495

Values are expressed as the mean ± standard deviation.
VAS: Visual Analog Scale; ODI: Oswestry Disability Index
Boldface with asterisk indicates statistical significance. p Value calculated using independent t tests

significantly related to ASD, but patient-related factors, fused levels, and sagittal alignment did not seem to contribute to ASD. Kyeong Hwan Kim et al. [2] evaluated the incidence of clinical and radiologic ASD and precipitating factors for clinical ASD in 69 patients with lumbar spondylolisthesis who underwent instrumented single-level interbody fusion at the L4-L5 level at more than 5 years after surgery, and reported that the occurrence of R-ASD and S-ASD was 84.0% and 24.0% respectively. Compared with patients with asymptomatic ASD, patients with S-ASD showed a significantly smaller lordotic angle at the L4-L5 level after operation. Maintaining the postoperative L4–L5 segmental lordotic angle at about 20° or more is beneficial for prevention of S-ASD. Hikono Aiki et al. [3] conducted a study including 117 patients who underwent posterior lumbar fusion and followed up for at least 2 years. They found that the re-operation rate was 7.7% in ASD cases associated with multilevel fusion. Georgios et al. [5] performed a retrospective cohort study among patients undergoing instrumented lumbar fusion for degenerative disorders (spondylolisthesis, stenosis, or intervertebral disc degeneration) with a minimum follow-up of 6 months, and found beyond fused level (OR=2.6) contributing to ASD.

Wang et al. [6] summarized that higher BMI, preoperative disc degeneration at the adjacent segment and intra-operative superior facet joint violation were risk factors for ASD.

The Lumbar Lordosis (LL) angle is also considered as a risk factor of ASD after lumbar spinal fusion. Matsumoto et al. [12] conducted a retrospective 1:5 matched case-control study including 20 patients who underwent revision surgery for symptomatic ASD after L4-5 PLIF and 100 patients who underwent L4-5 PLIF during the same period, and found no sign of symptomatic ASD, suggesting that pre- and postoperative lower LL were significantly associated with ASD. The above results indicate that the achievement of the appropriate LL may prevent ASD after lumbar spinal fusion. Ou et al. [20] stressed that BMI was a risk factor (OR=1.68) for ASD in patients undergoing lumbar fusion for degenerative spine disorders. An increase of 1 mean value in BMI would increase the ASD incidence rate by 67.6%. Controlling body weight before or after surgery may help reduce the occurrence of ASD.

Clinicians have developed various surgical techniques to deal with degenerative lumbar spinal stenosis for preventing ASD, such as application of Wallis interspinous implants and dynamic internal fixation systems in spinal surgery, but high medical costs limit their applications.

In the present study, we evaluated the radiographic and clinical results of extended fusion surgery using two different pedicle screw-insertion and fusion techniques. Based on the above mentioned factors of ASD, less trauma, favorable improvement of lumbar lordosis, and satisfactory clinical outcomes were considered as key indicators for superior surgical technique.

As showed in Table 2, 3, TPS-Domino-TLIF offered a shorter operative duration, smaller intraoperative EBL, a lower frequency of intra-operative fluoroscopy, and superior restoration of radiographic parameters compared with CBT-PLIF. The bone fusion rate at the operated level was similar between the two groups.

In our study, the LL angle obtained optimized the improvement rate in TPS-Domino-TLIF group owning to the correcting spinal sagittal alignment ability of the pedicle screws and rod system. It is worth noting that prebending of the rods is crucial for restoring the sagittal alignment. We feel that CBT screws and rods may not show superior correction potential for spinal sagittal alignment.

Many studies in recent years have addressed the comparison between CBT and TPS fixation in spinal fusion. Lee and Ahn [21] conducted a comparative study of CBT *vs.* TPS in single level PLIF, and reported that the fusion rate and clinical outcomes were similar between the two groups. Keorochana et al. [22] conducted a systematic review and meta-analysis based on eight studies to compare the outcomes of CBT and TPS in lumbar spinal fusion and found that CBT was comparable to TPS in terms of the clinical outcomes and fusion rates, but offered a lower incidence of complications and caused fewer traumas.

However, the use of CBT screw fixation technique in the treatment of ASD has only been reported in a limited number of studies. Lee and Shin [23] presented a minimally invasive surgical technique using CBT screw fixation for ASD after lumbar fusion surgery, and compared the postoperative outcomes between CBT and TPS at a 1-year follow-up period. They found that the bone fusion rate in 31 patients with TPS was 90% *vs.* 91% in 22 patients with CBT. Patient satisfaction at 1 month post-operation and pain intensity within 1 month post-operation were significantly better in CBT group than those in TPS group. In addition, CBT caused less blood loss and offered a shorter operation time and length of postoperative hospital stay. Chen et al. [24] also demonstrated the similar results through a technique note with case series in terms of cortical bone trajectory screw fixation in lumbar adjacent segment disease.

Unlike previous studies, our research showed that TPS-Domino-TLIF provided a shorter operative duration and less intraoperative EBL as compared with CBT-PLIF.

We analyzed several factors, including only two pedicle screws in TPS-Domino-TLIF group but four CBT screws needed in CBT-PLIF group, may contribute to less trauma in TPS-Domino-TLIF group.

In addition, the trajectory of CBT screws differs from the TPS trajectory, but preexisting pedicle screws at the index level sometimes impeded smooth implantation of the CBT screws. The relatively complex manipulation technique of the CBT screws prolonged the operation duration and cause larger trauma in CBT-PLIF group.

To surmount the obstruction of the preexisting pedicle screw to current CBT screws at the index level, deliberate preoperative preparation and accurate intra-operative monitoring need to be implemented.

Rodriguez et al. [25] introduced CBT screw fixation in the previously instrumented pedicle with the help of intra-operative O-arm guided navigation, which ensured accurate CBT screw placement.

Nevertheless, there was no O-arm imaging system in our institution. CBT screw implantation needs to be accomplished relying on surgeon's clinical experience, which prolongs the surgical duration, causes more blood loss, and increases the frequency of intra-operative fluoroscopy. On the other hand, improper location of the preexisting pedicle screws and anatomic variances, such as pedicle size and the extent of posterior decompression at the index level may make it impossible to implant CBT screws adequately at the caudal vertebra of the ASD level. Given the foregoing factors, we performed the surgery using conventional implants such as TPS and the Domino system.

Surgical technique with TPS and the Domino system for ASD has some advantages over CBT-PLIF for ASD. First, our method can be conducted with familiar implants such as TPS and the Domino system, which can be handled conventionally. Second, this manipulation can be performed easily without violating the index segments. Moreover, our outcomes with TPS-Domino-TLIF illustrated the similar fusion rate and clinical outcomes, and provided a shorter surgical duration, less blood loss, and a lower frequency of intra-operative fluoroscopy as compared with CBT-PLIF.

As most ASD patients are elderly with comorbidities that may influence the course of postoperative recovery, seeking a minimal invasive technique is paramount for these patients. Unlike of CBT screw implantation, TPS placement and assembly of the Domino system are easier to master for spine surgeons. TPS placement is a more familiar technique than CBT screw implantation owing to its long history of application in spine surgery. In addition, assembly of the Domino system and rods is a conventional procedure which can be handled easily. Furthermore, dural tear was found in one case in CBT-PLIF group due to severe dural sac adhesion. Compared with TLIF, manipulations in the spinal canal need to be performed more medially in PLIF at the expense of increasing risk for dural tear. Instrumentation failure was observed in one case of the CBT-PLIF and in one case of TPS-Domino-TLIF groups, respectively.

In the CBT-PLIF group, screw breakage was observed in one patient at 3 months follow up. One screw loosening in the TPS-Domino-TLIF group was observed at 6 months follow up. These two patients were observed closely with radiologic follow up and clinical status. Until the most recent follow up, the two patient's radiologic outcomes with regional kyphosis and clinical outcomes were satisfactory without further surgical intervention. After careful evaluation, screw failures in two patients could be caused by early physical activities and low BMD.

This study has several limitations. Firstly, it is a retrospective case control design, with a relatively small sample size of 72 patients (32 in CBT-PLIF group and 40 in TPS-Domino-TLIF group). To better establish the safety and efficacy of TPS-Domino-TLIF for ASD, further studies with larger sample sizes under a prospectively randomized design are needed. Secondly, we did not conduct a thorough preoperative evaluation of the radiologic parameters that may affect postoperative outcomes such as Sagittal Vertical Axis (SVA) and pelvic incidence-lumbar lordosis mismatch parameters [7,12]. Future studies should eliminate the bias regarding preoperative spinopelvic parameters. Thirdly, our study population had limited ranges of such characteristics as age and BMI, so the research results may not apply concordantly to all patient groups. Further studies with larger and more heterogenous patient cohorts are needed.

To the best of our knowledge, this is the first study to introduce and investigate a surgical technique for manipulating ASD after lumbar fusion surgery using TPS-Domino-TLIF. Moreover, our technique has significant advantages over CBT-PLIF for ASD, with a similar fusion rate and clinical outcomes but a shorter surgical duration, less blood loss and lower frequencies of intra-operative fluoroscopy. Thus, this study may serve as a cornerstone for future research to better evaluate the efficacy and safety of a surgical technique using TPS and the Domino system for ASD.

Conclusion

The results of this retrospective study demonstrated that the TPS-Domino-TLIF technique was aligned with a shorter surgical duration, less blood loss, lower frequencies of intra-operative fluoroscopy, and a better improvement rate of lumbar lordosis with similar clinical outcomes when compared to CBT-PLIF. It is safe to conclude that TPS-Domino-TLIF can possess a viable tactic to a revision surgery for S-ASD. Certainly, further studies are also needed to better assess the efficacy and safety of the minimally invasive techniques described herein.

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Authors' Contribution

Xin Song analyzed and interpreted the patient data, and was a major contributor in writing the manuscript. Donglin Ren performed surgery for all cases. Shuai Han helped preparing the dataset and participated in the discussion. Jian Wang and Desheng Wu designed the study. All authors read and approved the final manuscript.

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