Extended interbody fusion using cortical bone trajectory screws vs. traditional pedicle screws in the treatment of adjacent segment disease after transforaminal lumbar interbody fusion with pedicle screws: a retrospective case control study

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Research article

Keywords: adjacent segment disease, lumbar fusion, traditional pedicle screws, cortical bone trajectory screws

Posted Date: August 17th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-56120/v1

Abstract

Background

To present two minimally invasive surgical 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 two techniques for ASD.

Methods

Of the 36 patients included in this study, 16 patients received CBT-PLIF and the other 20 patients received TPS-Domino-TLIF. Patient demographics, surgical data, complications, radiologic and clinical outcomes were evaluated and compared between the two groups.

Results

The surgical duration of TPS-Domino-TLIF was significantly shorter than that of CBT-PLIF ($p < 0.001$). There was less estimated blood loss (EBL) and a lower frequency of intra-operative fluoroscopy in TPS-Domino-TLIF as compared with CBT-PLIF ($p < 0.001$). 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 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 ($p = 0.005$). The clinical outcomes in terms of the mean VAS-back, VAS-leg and ODI were improved significantly postoperatively in both groups.

Conclusions

As a more minimally invasive surgical technique for ASD, TPS-Domino-TLIF could be considered a viable alternative to the midline fusion technique using CBT.

Background

With the development of lumbar spinal fusion surgery, adjacent segment disease (ASD) has increasingly become a common concern in patients undergoing spinal fusion surgery [1–12]. Prior research has unveiled that the prevalence of radiographic ASD approximates up to 84% and that of symptomatic ASD ranges from 5.2–31% [2–3, 6, 11]. Abnormal biomechanical stress at the adjacent level or natural history in elderly people is considered to contribute to the occurrence of ASD. Normally, simple radiographic ASD may not need radical treatment. Only patients who present neurogenic claudication, lower extremity radiculopathy, or both, which is defined as symptomatic ASD, require standard conservative treatment. Patients who fail to respond to conservative treatment eventually need to be managed 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.

Several minimally invasive surgery techniques such as percutaneous endoscopic lumbar discectomy (PELD) have been gaining favor, but extremely rigorous indications limit their application for ASD in patients with spinal stenosis or instability. So far as we know, spinal fusion still plays a vital role in surgery for symptomatic ASD (S-ASD).

The cortical bone trajectory (CBT) screw technique, with biomechanical characteristics comparable to the traditional pedicle screws (TPS) technique[13–17], was initially introduced by Santoni et al in 2009 [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. We believed that the preexisting screws at the index level impeded the favorable CBT screws implantation. So, a novel Domino system combined with the TPS technique, which has been extensively used in scoliosis correction surgery, was utilized 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) to TPS fixation 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 for the treatment of S-ASD.

Methods

Patient selection

Upon approval from the institutional review board of the hospital, a retrospective cohort study was conducted containing 36 patients who underwent a single-level CBT-PLIF or TPS-Domino-TLIF in terms of S-ASD at a single academic institution from 2009 to 2018. All patients were followed up for at least 12 months. The mean age at the time of surgery was 68.3 (58–78) 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. There were 16 cases in CBT-PLIF group and 20 cases in TPS-Domino-TLIF group.

CBT-PLIF group (Fig. 1A-F): 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 8–9 degrees and a cephalad angle of 25–26 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 (Fig. 2A-F): Unlike CBT-PLIF group, the exposure in TPS-TLIF group was more laterally performed including the original terminal of the rod. Traditional pedicle screws implantation was accomplished at the proximal level except for the index level preexisting pedicle screws. Next, the procedures of TLIF were conducted regularly. Finally, new rods were linked and tightened firmly to the original rods bilateral using a novel Domino system (Bai Xin Medical Devices Company, Shanghai, China) (Fig. 3).

All screw implantation processes were monitored and confirmed by intra-operative fluoroscopy. The autograft bone fusion procedure was adopted in each patient. After confirming that the wound had healed favorably, discharge was scheduled and the patients were then followed up regularly. All patients were advised to wear the canvas corset for six weeks post-operation.

Clinical And Radiographic Data

The following demographic variables were collected from all patients: age, sex, body mass index (BMI) and the smoking status (SS). 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 collected from all patients preoperatively and postoperatively at 1-day, 2-week, 3-mong 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 plain 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 if 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.

Results

The symptoms were ameliorated remarkably after surgery in all patients. Demographic data, surgical duration, EBL, frequency of intra-operative fluoroscopy, radiological data, and clinical outcomes are illustrated in Table 1–4. The surgical duration in TPS-Domino-TLIF group was shorter than that in CBT-PLIF group (p < 0.001). EBL and frequency of intra-operative fluoroscopy CBT-PLIF group were higher than those in TPS-Domino-TLIF group (p < 0.001). The length of postoperative hospital stay was similar in both groups (p = 0.569).

Dural tear occurred in one case in CBT-PLIF group but no incision infection was observed during the follow-up period.

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 (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.

The mean VAS-back, VAS-leg and ODI in CBT-PLIF group were 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) 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) in TPS- Domino-TLIF group at the last follow-up.

Discussion

S-ASD has been found more frequent than used to be after spinal fusion so that clinicians should be alert 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 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 due 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 less trauma.

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 postoperation and pain intensity within 1 month postoperation 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 to 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.

This study has several limitations. Firstly, it is a retrospective case control design, with a relatively small sample size of 36 patients (16 in CBT-PLIF group and 20 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.

Conclusions

In this retrospective study, we compared two surgical techniques for ASD after lumbar fusion surgery: PLIF using CBT screw fixation, and TLIF using TPS fixation and Domino systems. The results demonstrated that the TPS-Domino-TLIF technique was associated 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. All these results suggest that the minimally invasive technique using TPS-Domino-TLIF provides a viable alternative to a revision surgery using CBT-PLIF for ASD. Further studies are needed to better establish the efficacy and safety of the minimally invasive technique described herein.

Abbreviations

CBT-PLIF
cortical bone trajectory screws with posterior lumbar interbody fusion
TPS-Domino-TLIF
traditional pedicle screws and a domino system with transforaminal lumbar interbody fusion
ASD
adjacent segment disease
EBL
estimated blood loss
S-ASD
symptomatic ASD
CBT
cortical bone trajectory
TPS
traditional pedicle screws
BMI
body mass index
SS
smoking status
PROs
patient-reported outcomes
VAS
visual analog scale
ODI
oswestry disability index
LL
lumbar lordosis
SVA
sagittal vertical axis

Declarations

Ethics approval and consent to participate

The study had been approved by the ethical committee of the participating hospitals. All subjects signed informed consent by each patient. All clinical investigations had been conducted according to the principles expressed in the Declaration of Helsinki.

Consent for publication

Consent for publication was obtained from every individual whose data are included in this manuscript.

Availability of data and materials

All data generated or analysed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests.

Funding

The clinical research projects were supported by the Academic leader Program of Pudong New Area Commission of Health and Family Planning (PWRd2017-08); the Science and Technology Development Funding of Pudong New Area (PKJ2017-Y33); the Pudong New Area Health System Key Speciality Project (PWZzk2017-015) .

Authors' contributions

XS analyzed and interpreted the patient data, and was a major contributor in writing the manuscript. DR performed surgery for all cases. SH and FZ helped prepare the dataset and participated in the discussion. JW designed the study. All authors read and approved the final manuscript.

Acknowledgements

Not applicable.

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Tables

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	0.580
Sex:M/F	9/7	12/8	1.000
BMI in kg/m2	29.1±2.9	29.0±2.3	0.868
Smoking:Yes/No	7/9	9/11	1.000
DM:Yes/No	9/7	11/9	1.000

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 χ2 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).

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 improvement rate(%)	21.5±7.5	39.0±22.9	**0.006***
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 improvement rate(%)	24.7±8.6	44.2±32.2	**0.025***
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	90.0	1.000

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 χ2 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.

Figures

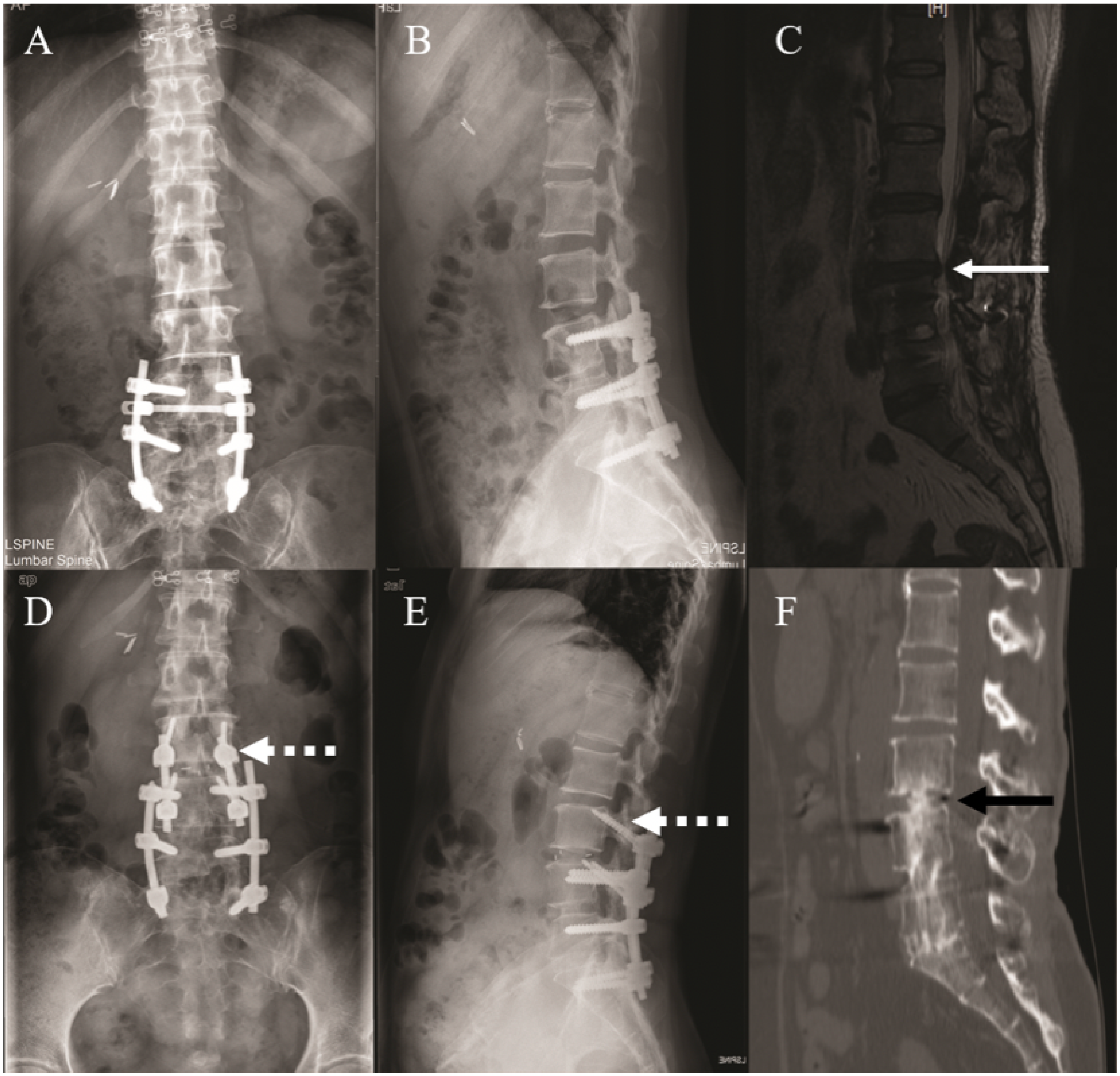

Figure 1

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).

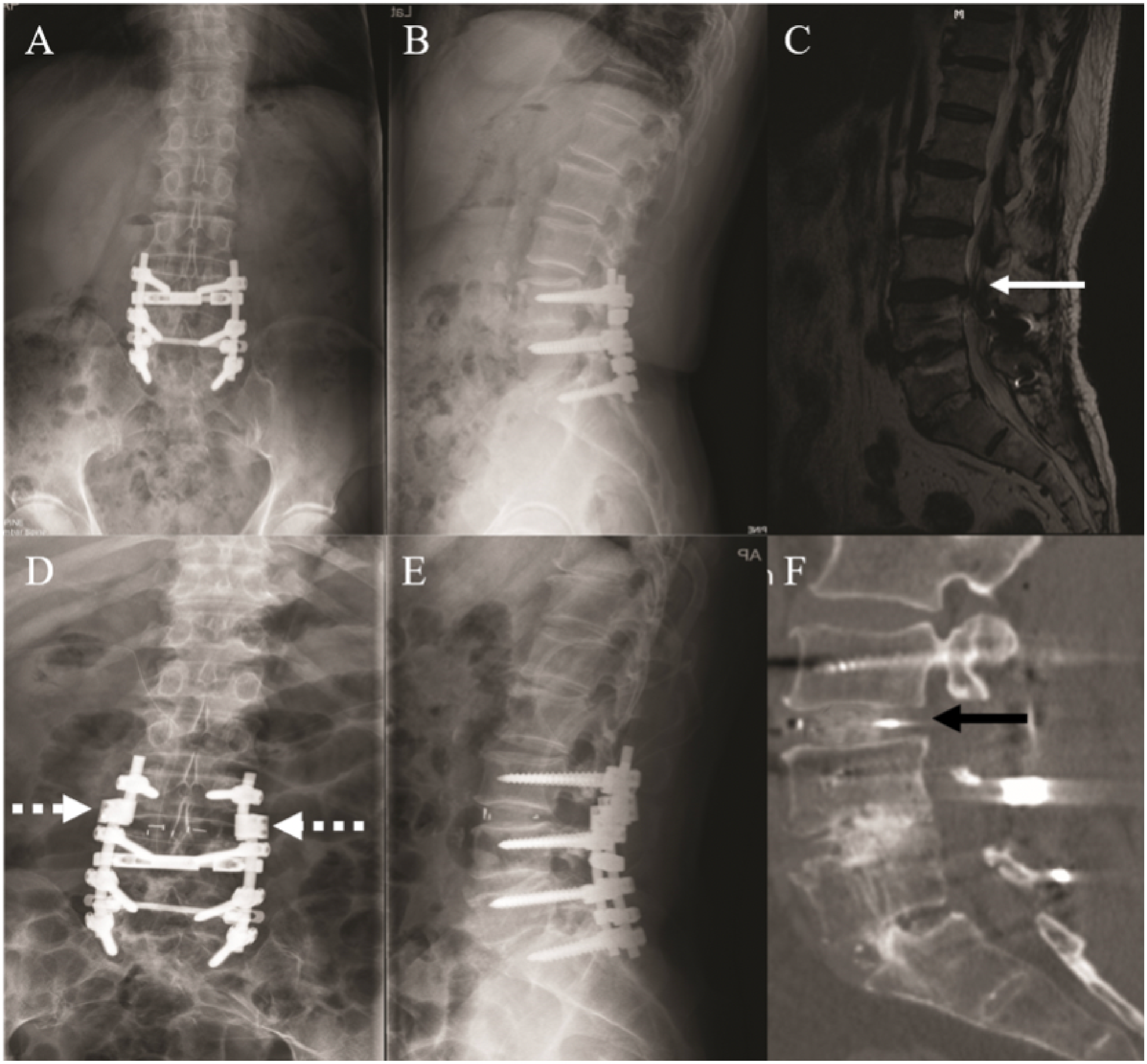

Figure 2

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).

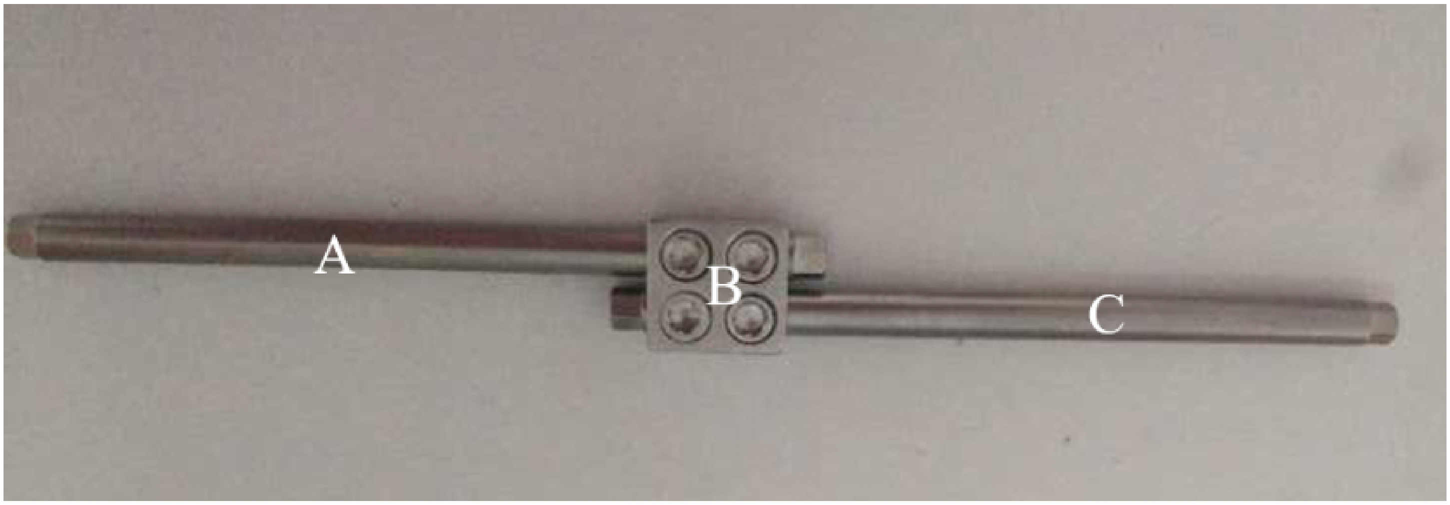

Figure 3

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.