

# Effect of the Short-Segment Internal Fixation with Intermediate Inclined-Angle Screw at the Fractured Vertebrae on the Treatment of Denis type B thoracolumbar fracture

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## Research article

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# Abstract

**Background** Short-segment internal fixation with straight-forward screw (SSIF-SF) and long-segment internal fixation (LSIF) are two major surgical options for thoracolumbar (TL) fracture, however, limitations of two surgical options are obvious. SSIF with inclined-angle screw (SSIF-IA) have been lately developed to take advantage of their benefits and minimize their adverse effects.

**METHODS** Three different treatments were randomly performed in 69 consecutive TL fracture. 26 were allocated to treatment with SSIF-IA, 24 were assigned to treatment with SSIF-SF, 19 patients were randomized to treatment with LSIF. Sagittal Cobb's angle (SCA), anterior vertebral body height (AVBH), vertebral body index (VBI) and spinal canal encroachment (SCE) were measured and assessed. Functional recovery Visual Analogue Scale (VAS) and Oswestry disability index (ODI) were also evaluated.

**RESULTS** The value of incision length, mean blood loss, duration of operation and hospital stay in the SSIF-IA group and SSIF-SF group were significantly lower than those in the LSIF group. During 6 months and the latest follow-ups, the AVBH and VBI in the SSIF-IA group and LSIF group were significantly more improved than those in the SSIF-SF group ( $p < 0.05$ ). The correction losses of AVBH and VBI of the fractured vertebrae in the SSIF-IA group and LSIF group were significantly lower than those in the SSIF-SF group ( $P < 0.05$ ). There was no significant difference of SCA among three groups. The average ODI scores in SSIF-IA and SSIF-SF group were significantly lower than those in the LSIF group.

**CONCLUSIONS** The bio-mechanical stability of SSIF-IA was comparable to LSIF, but less invasive as compared with LSIF. SSIF-IA was effective and reliable operative technique for patients with Denis type B TL fracture.

## Introduction

The thoracolumbar (TL) junction is a transition zone between the rigid thoracic spine and the more mobile lumbar spine (from T11 to L2), and nearly 70 % of all traumatic spinal injuries occur within this region [1, 2]. The treatment of TL fracture remains under debate, especially in patients without serious neurological symptoms. Although conservative treatment seems to be effective in the majority of patients, clinical studies have shown that surgical treatment provides better fracture reduction, stronger fixation and long-term clinical outcomes [3, 4]. The posterior approach is often applied for the surgical management of TL fracture [5, 6]. There are two main reasons for this choice. Firstly, more postoperative morbidities are accompanied with the anterior approach as compared with the posterior approach [7-9]. In addition, spine surgeons are more familiar with posterior approach due to its easier application [10].

Short-segment internal fixation (SSIF) via posterior approach is the most common treatment for TL fracture [11]. Although SSIF can obtain satisfactory reduction, it often led to instrumentation failure due to osteoporosis and correction loss [12]. Long-segment internal fixation (LSIF) is an alternative solution, which is more stiffer and reduce the load on each screw by the application of longer segmental

instrumentation, however, the LSIF is unnecessarily extensive and decrease the flexibility of motion segments. In addition, the LSIF is often associated with the development of adjacent-segment degeneration (ASD) disease [13-15]. Saving the motion segments is the crucial principle of the spinal surgery. Therefore, in order to limit the number of the fusion segments and improve instrumentation efficiency, additional intermediate screws inserted at the fracture level is clinical applied along with SSIF to treat TL fracture[16, 17]. The intermediate screws in this SSIF system were usually paralleled with the superior endplate with relatively short length[18]. However, as a result of collapse of anterior and middle columns in TL fracture, SSIF with straight-forward screws can't often offer sufficient biomechanical support for the anterior column[19].

Recently, studies [20, 21] have shown that relatively long length pedicle screws could significantly reduce the pull-out force and increase the stiffness of the fixation. We subsequently modified the traditional SSIF with straight-forward screws and developed a new technique for the TL fracture. We changed the direction of implementation of pedicle trajectory as compared with standard implementation, and applied more inclined angle and longer pedicle screws at the fracture level. These intermediate screws traverse all three columns of the vertebral bodies, which can enhance the interface strength and contribute to greater stability with SSIF [22, 23]. Therefore, a retrospective study was conducted to compare the feasibility, safety, and efficacy of the SSIF with inclined-angle screw with the SSIF with straight-forward screw and the LSIF in the treatment of Denis type B TL fracture.

## **Material And Methods**

### **Patient population**

Seventy-eight consecutive patients met the criteria for inclusion. Five patients refused the surgical treatment, and four were lost to follow-up. 69 patients (47 males and 22 females), ranging from 22 to 54 years old (average 34.5 years) were enrolled in this study. Only patients with a single-level TL junction (T11–L2) fracture were included and received surgical management in our department between May 2011 and May 2015. Patients were divided into three groups: 1. SSIF-IA: SSIF with intermediate inclined-angle screw at the fracture level; 2. SSIF-SF: SSIF with intermediate straight-forward screw at the fracture level; 3. LSIF: Long-segment internal fixation using two pedicle screws above and below the fracture level (Figure 1).

The study was approved by the Ethics Committee of General Hospital of Central Theater Command and were in accordance with the Helsinki Declaration. Written informed consent was obtained from each patient. Randomization was conducted based on a computer-generated random allocation sequence. 26 were allocated to treatment with SSIF–IA (treatment group), 24 were assigned to treatment with SSIF–SF (control group), 19 patients were randomized to treatment with LSIF (control group).

### **Inclusion and exclusion criteria**

The inclusion criteria were: Denis type B TL fracture, no unstable fracture dislocations, absence of obvious neurological impairment (Frankel grade A and B), and from trauma to operation being less than one week. The exclusion criteria were: The fractured inferior endplate that was confirmed by computed tomography (CT) scans, pathologic fracture, osteoporotic fracture, bilateral pedicle fracture, previous spinal surgery history, other major organ system injuries, pregnancy.

## **Surgical procedures**

After induction of general anesthesia with endotracheal intubation, each patient was placed in the prone position on a specialized operating frame that both shoulders and superior iliac spines were supported by gel pads to create hyperextension position of the spine and perform postural reduction. In the SSIF–IA group, after determination of the fracture level under fluoroscopy, a midline vertical skin incision was made to split psoas muscle and expose the desired lumbar spine level adequately. Four pedicle screws were bilaterally implanted into adjacent vertebrae above and below the fracture level. For the fractured vertebrae, a “L”-shaped chisel was inserted into the fractured vertebrae to reduce the compressed bone tissues. The superior endplate was injured, and the inferior endplate was intact in the Denis type B TL fracture, the starting point was 3mm superior to the standard landmark, and the pedicle screws insertion was approximately 5 degrees inclined to the inferior endplate. Unilateral or bilateral pedicle screws were placed according to the integrity of the pedicle in the fractured vertebrae. The inclined-angle pedicle screws were purchased in the residual lower portion of the injured vertebral body. After the all pedicle screws were attached, two rods connected pedicle screws on both sides using the special placement system. The reduction and fixation were confirmed under fluoroscopy, and the incision was then irrigated and sutured. All operations were performed by the same surgery group. The procedures for the LSIF and SSIF–IA were described as previously [16]. Only one instrumentation technique without grafting fusion was utilized. If no spinal canal decompression was observed before operation, pedicle screws can also be implanted percutaneously under C-arm fluoroscopic guidance. The internal fixation stabilization system was supplied by Shandong Weigao Company of China.

All patients were routinely administered prophylactic antibiotics postoperatively for 48 hours, and the sterile dressing of incision was replaced very 2 days until the suture was removed. Patients were encouraged to start physical activities under the protection of brace, however, excessive and heavy activities were restricted up to 12 weeks after the operation. Following discharge from the hospital, patients were clinically and radiologically assessed at monthly intervals in the orthopedic outpatient clinic, with a mean follow-up of 24.01 months (range, 18–36 months).

## **Clinical Assessment**

The clinical data from all included patients were obtained and assessed. We evaluated each patient by using Visual Analogue Scale (VAS) and Oswestry disability index (ODI) questionnaires, preoperatively and at each follow-up (1 week, 6 months and the latest follow-up). The VAS and ODI scores were recorded in the questionnaires at each follow-up in the orthopedic outpatient clinic.

Radiographic evaluation consisted of sagittal Cobb's angle (SCA), anterior vertebral body height (AVBH), vertebral body index (VBI) and spinal canal encroachment (SCE). The SCA, AVBH and VBI were measured as previously described[17]. The SCE was obtained from serial transverse CT scans by using Image J (NIH, Bethesda, MD) on admission and immediately after surgery, and to evaluate the extent of the spinal canal decompression [24]. All the data were analyzed by an independent observer who was not involved in the treatment of patients.

### **Statistical analyses**

The Chi-square tests and Mann-Whitney U test were performed to analyze the variables calculated by SPSS 17.0 software (SPSS Inc, Chicago, USA). Quantitative data were represented as the mean  $\pm$  standard deviation, and a statistical significant difference with P value < 0.05.

## **Results**

### **Demographic characteristics**

Baseline demographic data, age, gender, cause of injury and fracture site and neurological status in three groups were presented in Table 1. No significant differences were observed among three groups. The injured vertebrae segments were T11 in 7 patients, T12 in 14 patients, L1 in 31 patients, and L2 in 17 patients. The fractures were caused by traffic accidents in 25 patients, falling from height in 30 patients, and other accidents in 14 patients (Table 1).

The average incision length was 10.4 cm (7.2-16.3 cm). The mean blood loss was 110 ml (30–450 ml) during operation. The average duration of operation was 122.4 mins (98–155 mins). The median hospital stay was 14.8 days (10–22 days). The most common reason for the delay was financial constraint. There were no significant differences between the SSIF–IA group and the SSIF-SF group with regard to incision length, mean blood loss, duration of operation and hospital stay. The value of these parameters in SSIF–IA group and SSIF-SF group were significantly lower than those in the LSIF group (Table 2).

### **Radiologic outcomes**

Significant improvements from baseline in the SCA, AVBH, VBI and SCE of the fractured vertebrae were observed among three groups ( $P < 0.05$ ). The SCA in the LSIF group was significantly more improved than those of SSIF-SF group at 6 months ( $P < 0.05$ ), however, there was no significant difference of SCA between the SSIF-IA group and SSIF-SF group post-operatively ( $P > 0.05$ ). The AVBH in the SSIF-IA group and LSIF group (from  $84.8 \pm 7.2$  to  $78.2 \pm 7.3$ ; from  $84.3 \pm 9.4$  to  $78.9 \pm 8.9$ ) were significantly more improved than those of SSIF-SF group (from  $82.1 \pm 7.2$  to  $73.3 \pm 9.3$ ) at 6 months and the latest follow-ups ( $P < 0.05$ ). The VBI in the SSIF-IA group and LSIF group (from  $87.9 \pm 9.2$  to  $84.2 \pm 8.7$ ; from  $88.1 \pm 8.9$  to  $85.1 \pm 8.5$ ) were significantly more improved than those of SSIF-SF group (from  $87.9 \pm 7.9$  to  $79.4 \pm 7.2$ ) at 6 months and the latest follow-ups ( $P < 0.05$ ). There were no significant differences of SCE among three groups post-operatively ( $P > 0.05$ ) (Table 3).

During 6 months and the latest follow-ups, the correction losses of AVBH of the fractured vertebrae in the SSIF-IA group and LSIF group (from  $5.6 \pm 3.9\%$  to  $7.6 \pm 4.5\%$ ; from  $4.5 \pm 1.3\%$  to  $6.3 \pm 1.4\%$ ) were significantly lower than those in the SSIF-SF group ( $8.8 \pm 5.9\%$  to  $10.9 \pm 6.5\%$ ) ( $P < 0.05$ ); Similarly, the correction losses of VBI of the fractured vertebrae in the SSIF-IA group and LSIF group (from  $2.9 \pm 1.6\%$  to  $4.2 \pm 1.6\%$ ; from  $2.1 \pm 0.6\%$  to  $3.5 \pm 0.5\%$ ) were significantly lower than those in the SSIF-SF group ( $8.2 \pm 2.1\%$  to  $9.7 \pm 2.1\%$ ) ( $P < 0.05$ ); However, there were no significant differences of correction losses of SCA among three groups ( $P > 0.05$ ) (Table 4).

## Clinical outcomes

The average VAS scores following surgery improved in three groups. The average VAS scores were significantly reduced immediately from  $8.5 \pm 1.1$  to  $1.6 \pm 0.7$  in the SSIF-IA group, from  $8.6 \pm 1.1$  to  $1.7 \pm 0.7$  in the SSIF-SF group, and from  $8.6 \pm 1.1$  to  $2.2 \pm 0.7$  in the LSIF group. There were no significant differences of the average VAS scores at the pre-operation and 1-week follow-up among three groups, however, the average VAS scores in the SSIF-IA group and SSIF-SF group were significantly lower than that in the LSIF group at the 6 months and the latest follow-ups.

The average ODI scores following operation also improved. The average ODI scores were significantly reduced immediately at post-operation from  $79.2 \pm 7.0$  to  $26.3 \pm 9.0$  in the SSIF-IA group, from  $74.7 \pm 9.6$  to  $27.3 \pm 8.1$  in the SSIF-SF group, and from  $74.1 \pm 12.4$  to  $32.3 \pm 6.1$  in the LSIF group. Similarly, there were no significant differences of the average ODI scores at the pre-operation and 1-week follow-up among three groups, however, the average ODI scores in the SSIF-IA group and SSIF-SF group were significantly lower than that in the LSIF group at the 6 months and the latest follow-ups (Table 5).

## Complications

No major complications, such as nerve injury, wound infections, non-fusion etc., occurred among three groups postoperatively. One case of screw breakage at the 6-month follow-up, with a 4.16% failure rate in

the SSIF-SF group, and one case of screw loosening at the 1-year follow-up, with a 5.26% failure rate in the LSIF group, however, there were no difference between the 2 groups concerning failure rate ( $P= 0.87$ ). Both patients underwent conservative treatment until solid bony fusion of the superior vertebrae was observed, and then the implant was removed. All patients with incomplete neurological impairment in the three groups improved at least one grade according to Frankel performance scale. Functional recovery (Frankel Grades D or E) was observed in all patients postoperatively.

## Representative cases

Representative case who underwent operation via inclined-angle screw placement was illustrated in Figure 2.

## Discussion

Although the conservative management was thought to be the optimal treatment of TL junction fracture without serious neurological impairment, it is often accompanied by discomfort and limited mobility. Surgical intervention is therefore preferred in patients with TL junction fracture, because it can maintain the reduction, prevent further deformity and neurologic deterioration, and improve mobilization. The selection of the surgical approach in the treatment of TL junction fracture is dependent on many variables, such as bone intensity, kyphotic deformity, spinal canal encroachment etc.. Either anterior, posterior approach or combined approaches can be applied for the stabilization of the unstable spine. Studies have shown that anterior instrumentation with grafting can achieve reliable internal fixation, but it requires a more invasive approach that is associated with morbidities and prolonged postoperative recovery [8, 25]. Alternative technique was considered prior to this more invasive approach. Isolated posterior approach can also be applied to recover the stability of middle and anterior column. The LSIF via posterior approach can provide enough rigidity and stiffness of the spine, however, it might decrease spinal range of motion and increase the incidence of ASD. Therefore, some other improved alternatives have been lately developed to take advantage of its benefits and minimize its adverse effects.

Superior biomechanical stability was found in SSIF with the addition of pedicle fixation at the fracture level without sacrificing the benefits of SSIF. Studies have shown that SSIF with intermediate screws insertion improved rigidity to flexion forces, which was 1.8-fold of that of SSIF [11, 26]. Moreover, clinical research has found that the preservation of the fractured vertebrae height obtained in SSIF with intermediate screws was equivalent to that of LSIF [18]. Secondly, the use of intermediate screws at the fracture level can optimize internal fixation strength load and reduce the risk of broken screws or rods. Buckling of rod was more evident within the four-screw fixation construct than that within the six-screw fixation construct[27]. This is due to that the rod of the four-screw fixation construct spans a longer distance between two screws as compared with six-screw fixation construct, tension strains at two levels for the four-screw fixation construct were significantly higher than that at every levels for the six-screw fixation construct [28, 29]. Although traditional SSIF with intermediate screws theoretically corrects

kyphotic deformities, however, the present instrumentation is not able to provide adequate support to the injured anterior spine column for unstable TL fracture in practice.

We then developed a new strategy for the SSIF with inclined-angle intermediate screws. There are some advantages as following: Firstly, this inclined-angle screw placement increases the length of pedicle screws, so it can provide greater construct stiffness and increase the pullout force of screws. Denis type B fracture is a special categorized fracture, in which the superior endplate is mainly involved, while the inferior endplate and the lower portion of the injured vertebral body usually escapes from the injury site[30]. The lower portion of the injured vertebral body and the caudal disc are preserved and residual vertebral body are able to tolerate anterior column reconstruction. The pedicle screws in the SSIF-IA group were inserted into the lower portion of the intact vertebral body, which would in turn contribute to the pullout strength. Secondly, the “eggshell” deformity often occurred and the injured vertebrae can't provide enough construct stiffness during the healing process of fractured vertebrae[31]. The potential reason for the “eggshell” effect is that the vertebral height is fully restored by the internal fixation device, but the compressed bone trabeculae are not restorable, which results in a vertebral body with lack of bone integrity [32]. To prevent this, several techniques have been developed to augment the anterior column in the unstable fractures, such as polymethylmethacrylate (PMMA) injection, however, injection of PMMA into a fractured vertebral body may often lead to cement extrusion into the spinal canal, particularly when the posterior longitudinal ligament is torn[33]. The inclined-angle screw placement might push the residual vertebral body tissues above the screws up to the eggshell-like cavity caused by the “eggshell” effect, and then the defect would eventually be filled with bone tissue. It might possibly reduce the negative effects caused by the “eggshell” deformity, and increase the stability capability during the fracture healing process. During the follow-up period of over 2 years, none of the patients in the SSIF-IA group exhibited loosening or shifting of the intermediate screw at the fracture level. The main reason for this difference might be due to that the anterior and middle spinal columns of our patients were immediately strengthened by the inclined-angle screws. It suggests that inclined-angle screws at the fracture level can improve construct stiffness and protect the fractured vertebral body from anterior loads, however, additional biomechanical study needed to be conducted to verify this speculation.

This prospective study evaluated the radiological outcomes of 69 patients with TL fracture who were treated with three different internal fixations. As it was observed in the current study, SSIF with intermediate inclined-angle screws provided better postoperative correction and maintenance than SSIF with intermediate straight-forward screws. The initial correction of AVBH and VBI of the SSIF-IA group (AVBH from  $64.3 \pm 9.0$  to  $84.8 \pm 7.2$ ; VBI from  $55.2 \pm 10.1$  to  $87.9 \pm 9.2$ ) were better than those of the SSIF-SF group (AVBH from  $63.0 \pm 9.4$  to  $81.7 \pm 7.2$ ; VBI from  $53.7 \pm 7.9$  to  $87.9 \pm 7.9$ ). Moreover, the correction losses of the AVBH and VBI of the SSIF-IA group (AVBH from 5.6–7.6%; VBI from 2.9–4.2%) were significantly lower than those of the SSIF-SF group (AVBH from 8.9–10.9%; VBI from 8.2–9.7%) at the 6 months and the latest follow-ups. Similar to the previous study [34], there was no statistical difference for the correction losses of the SCA observed between the two groups, and intermediate screws insertion at the fracture level didn't achieve greater correction of kyphotic angle. No statistical difference of the SCA among three groups is due to no significant correlation between canal narrowing and neurological

encroachment, which is dependent on the injury of spinal cord occurs at the time of trauma[35]. Only patients with minor neurological impairment (Frankel grade C, D and E) were included in our study, and all of them gradually recovered thereafter. Although the correction and maintenance of the fractured vertebral body was the best in the LSIF group, however, from a statistical point of view, the statistical difference for the correction losses between the SSIF-IA and LSIF was not significant. Our data supported that the SSIF-IA was comparable to the LSIF, and it also can offer improved fixation and better correction than the SSIF-SF in the TL junction fractures.

Similar to the previous study, the values of all considered parameters (incision length, blood loss, surgical duration and hospital stay) in the LSIF were the highest among three groups, however, no significant differences were observed for these parameters between the SSIF-IA group and SSIF-SF group. Moreover, significant improvements of functional outcomes (VAS back pain and ODI) were obtained in the SSIF-IA group and SSIF-SF group as compared with that in the LSIF group at the 6-month and the last follow-up. Favorable surgical outcomes can be defined by 15% improvement in ODI score[36], and our data were consistent with this criteria. In addition, it was found that ODI score is associated with VAS and SF-36[37]. The ODI changes might be explained by the corresponding VAS changes in our study. These results suggested that intermediate inclined-angle screws insertion at the fracture level didn't increase the operation duration and the blood loss as compared with the traditional straight-forward screws insertion.

Alvine et al. [38]reported that 39% screw breakage was found and 23% reoperation was performed. McLain et al. [39]have shown that instrumentation failure incidence was more than 50 percent. In our series, instrumentation failure occurrence was lower than that reported in these studies, one case of screw breakage in the SSIP-SF group and one case of screw loosening in the LSIP group (instrumentation failure rate = 2.90%). One screw breakage above the fracture level was observed at the 6-month follow-up in a 28-years old man (instrumentation failure rate = 4.16%). We attributed the reason for this instrumentation failure to the increased stress on the pedicle screw. This man had a history of heavy work without brace protection postoperatively. One screw loosening occurred at the 1-year follow in a 72-years old woman (instrumentation failure rate = 5.26%). This patient was diagnosed as osteoporosis preoperatively, however, she didn't follow the doctor's advice and take medicine against osteoporosis regularly during the follow-up.

There are still several limitations to this study. First, underlying factors such as, the bone density, degree of disc degeneration, and vertebral size, are variable. These confounding factors were offset by investigating three internal fixation strategies in the same specimen. In addition, this study evaluated short-term clinical outcomes, and findings may be biased, long-term stability of implants should be considered. Lastly, a small population of patients was included in this study. More patients should be enrolled to properly evaluate the feasibility of this technique.

In conclusion, the SSIF-IA can exert greater strength on the fractured vertebrae and effectively maintain the height of fractured vertebrae as compared with SSIF-SF; Compared with the LSIF, the SSIF-IA can minimize the number of fused levels, and promote rapid relief of lumbar back pain and early

rehabilitation. We recommended that SSIF with inclined-angle screws was effective and reliable operative technique for patients with Denis type B TL fracture.

## Abbreviations

SSIF: Short-segment internal fixation; SSIF-IA: Short-segment internal fixation with inclined-angle screw; SSIF-SF: Short-segment internal fixation with straight-forward screw; LSIF: Long-segment internal fixation; TL: thoracolumbar; SCA: Sagittal Cobb's angle; AVBH: Anterior vertebral body height; VBI: Vertebral body index; SCE: Spinal canal encroachment; VAS: Visual Analogue Scale; ODI: Oswestry disability index.

## Declarations

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Not applicable.

### Research registration number:

Not applicable.

### Disclaimer:

On behalf of all authors, the corresponding author states that there is no conflict of interest.

### Author contributions:

FX and HK have designed the study, and performed the operations. JW have collected the data. CX have analyzed the data and made the statistics. BH have written the manuscript. All authors read and confirmed the final manuscript.

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### Availability of data and materials:

The datasets for this study are available from the corresponding author on reasonable request.

### Ethics approval and consent to participate:

Written informed consent was obtained from each patient included in the study. This study was according to the Helsinki Declaration and was approved by the local ethics committee.

### Consent for publication:

Not applicable.

### Competing interests:

No competing interests were declared.

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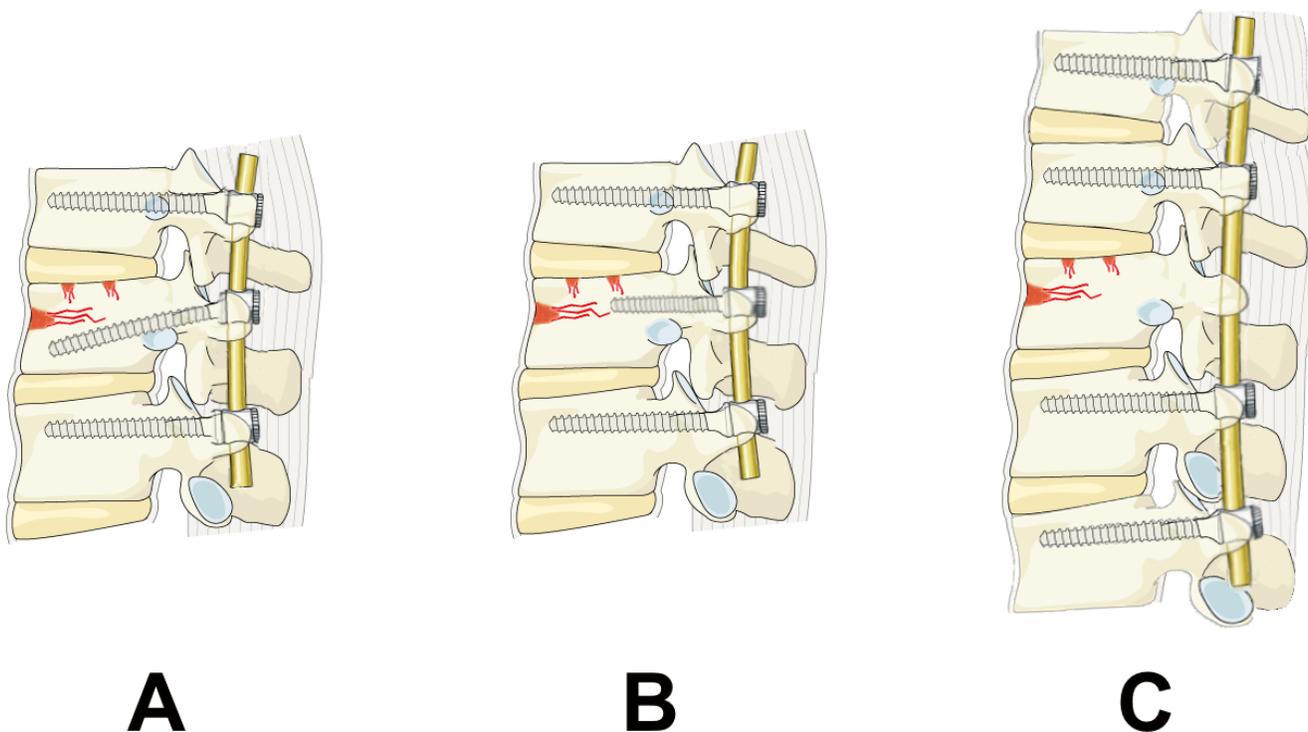
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## Tables

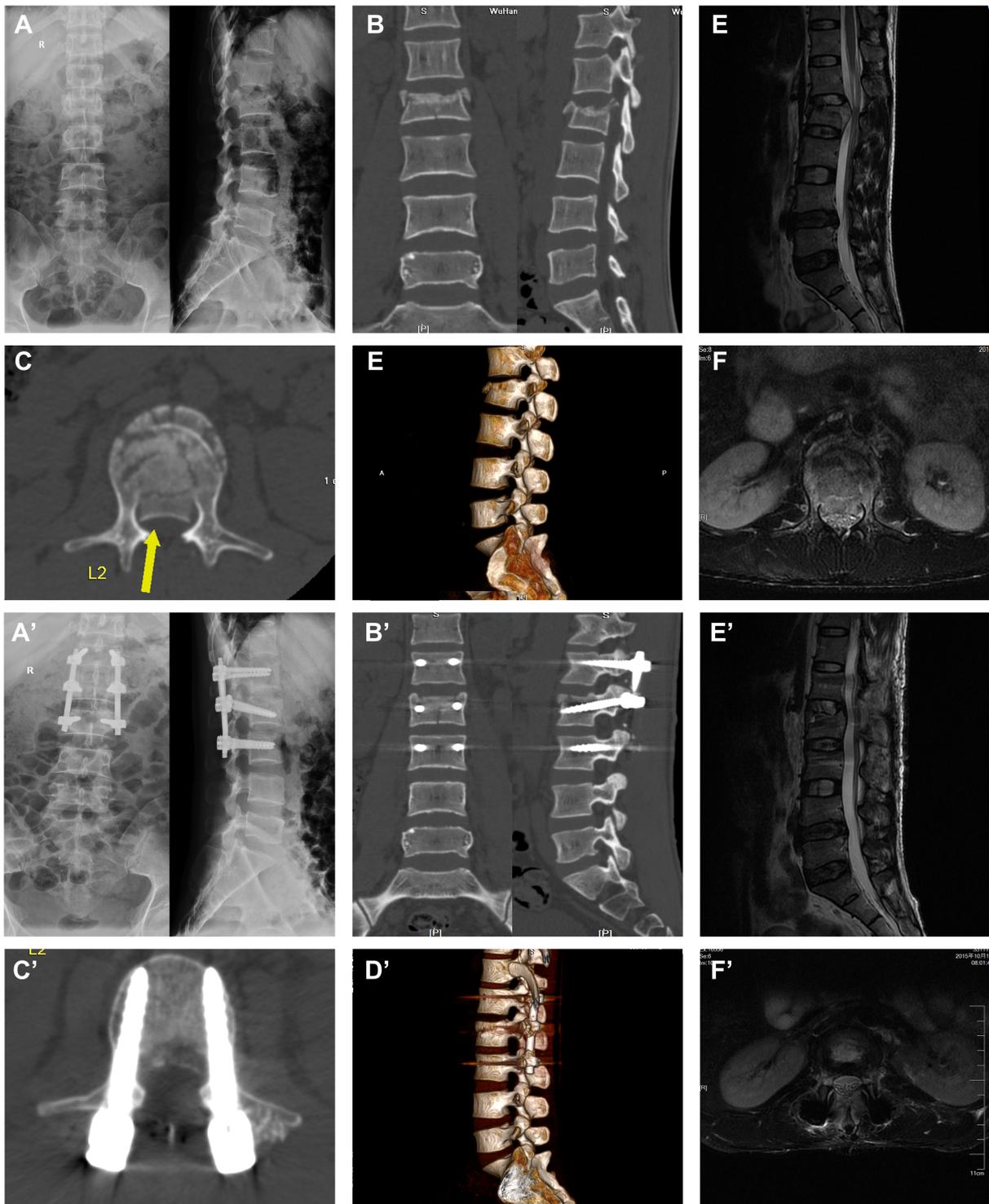
Please see the supplementary files to access the tables.

## Figures



**Figure 1**

The illustration of three different fixation on the treatment of Denis type B TL fracture. A: Inclined-angle screws were inserted at the fracture via the posterior approach along with SSIF; B: Straight-forward screws were inserted at the fracture via the posterior approach along with SSIF; C: Two pedicle screws above and below the fracture level were inserted via the posterior approach along with LSIF. TL: thoracolumbar; SSIF: short-segment internal fixation; LSIF: Long-segment internal fixation.



**Figure 2**

X-Ray, CT and MRI of a case with Denis type B TL fracture treated by SSIF-IA system. A and A': Anteroposterior and lateral X-Ray demonstrating the L2 compression fracture before and after operation; B: Lateral spiral CT showing the L2 fracture with injured superior endplate before and after operation; C: Axial spiral CT showing the spinal canal encroachment by fragments of fracture vertebra before and after operation; D: The 3D reconstruction of lumbar spine with L2 compression fracture before and after

operation; E: Sagittal MRI confirming the L2 compression fracture with vertebra edema before and after operation; F: Axial MRI confirming the spinal canal encroachment by fragments of fracture vertebra along with posterior elements of the vertebrae before and after operation. CT: computer tomography; MRI: magnetic resonance imaging; 3D:3-dimension.

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