Chapter

Short-Segment Schanz Pedicle Screw Oblique Downward Fixation for Thoracolumbar Burst Fractures: A New Method for the Reduction of Intraspinal Bone Fragments

Sheng Yang and Chunyang Xia

Abstract

Short-segment pedicle screw internal fixation for thoracolumbar burst fracture has been widely used in clinic. When the fracture fragment enters the spinal canal seriously, it is often necessary to decompress. The authors pioneered the reduction of fracture fragments in the spinal canal by direct traction with pedicle screws implanted obliquely downward without lamina decompression. Compared with the previous pedicle screw parallel endplate fixation and lamina decompression, this new method has less trauma, better reduction and can remove the internal fixation after fracture healing. Compared with conventional pedicle screws, short-segment Schanz pedicle screws are more similar to normal posterior columns in structure and stress conduction and have better safety and stability, so the latter is more suitable for the treatment of severe burst fractures.

Keywords: thoracolumbar spine, burst fracture, short-segment pedicle screw, obliquely downward fixation

1. Introduction

Thoracolumbar spinal fracture is the most common spinal fracture. When the fracture is serious, it often needs surgical treatment [1–5].Previous studies have shown that it is difficult to reduce the intraspinal fracture fragments by direct distraction when the displacement distance is >0.85 cm, the turnover angle is >55° [6], the transverse diameter of fracture block/injured vertebral is >75%, and the height of displaced fracture block/injured vertebral height is >45% [7]. In this case, laminectomy combined with anterior surgery is usually required to directly reduce or treat intraspinal bone fragments. In 2018, the authors first reported a direct distraction and reduction of such intraspinal bone fragments by oblique downward insertion of Schanz pedicle screws in the adjacent upper and lower vertebrae without laminectomy and/or anterior surgery[8].In this article, the authors will discuss the scoring criteria of thoracolumbar injuries, the advantages of Schanz screws, the mechanism of oblique downward screw distraction reduction, the indications and contraindications of the new method, and the role of thoracolumbar orthosis.

2. Thoracolumbar injury score criteria

Currently, commonly used scoring systems for thoracolumbar injury include Thoracolumbar Spine Injury Classification System (TL AOSIS) [3, 4], Thoracolumbar Injury Classification and Severity Score (TLICS) [2] and Load Sharing Classification (LSC) [5].Both TLICS and TLAOSIS score thoracolumbar fractures from three aspects: fracture morphology, integrity of the posterior ligament complex (PLC), and nerve injury. Conservative treatment is recommended when the total score of TLICS is less than 4, and surgical treatment is recommended when the total score of TLICS is more than 4, and both are acceptable when the total score of TLICS is 4 [2].TLAOSIS classifies neurological dysfunction on the basis of TLICS and adds clinical correction parameters. Conservative treatment is recommended when the total score of TLAOSIS is ≤3, surgery is recommended when it is >5, and surgery or conservative is recommended when it is 4–5 [3, 4].

Different from TLICS and TLAOSIS, LSC quantified and assigned values from three aspects, such as vertebral fracture degree, fracture block displacement range, and kyphosis correction angle. Each aspect was recorded as 1 point, 2 points, and 3 points, respectively, according to light, medium, and heavy, and the highest was 9 points [5]. Conservation is recommended when the total score of LSC is less than 4 points, and short-segment pedicle screw fixation is recommended when the total score of LSC is 4–6 points; posterior short segment fixation is not suitable when the total score is ≥7, and anterior fixation is recommended [5]. LSC only makes a detailed assessment of vertebral injury, but lacks the assessment of neurological function and posterior column (PLC), so it is not suitable to use LSC alone for assessment when combined with neurological and posterior column injuries. TLICS and TLAOSIS are more comprehensive in evaluating fractures than LSC, but their evaluation of fractured vertebral bodies is not detailed/lacks quantitative standards, so the authors use LSC + TLAOSIS to evaluate thoracolumbar fractures clinically.

LSC is an evaluation standard for judging the safety of short-segment pedicle screw fixation in the treatment of thoracolumbar fractures [5]. The higher the LSC score, the more unstable the injured vertebra and the worse the safety of short-segment pedicle screw fixation. Since this article mainly discusses the treatment of thoracolumbar burst fractures with pedicle screw fixation, the authors use LSC to evaluate the severity of fractures in this article. The accuracy of LSC has been questioned in recent years [9, 10]. Filgueira et al. reported in 2020 that LSC is safe and reliable when LSC is ≤6, and when LSC is ≥7, it is necessary to combine other evaluation criteria to select appropriate surgical methods [11]. Similarly, the author's finite element study on short-segment (T12 and L2) Schanz screw fixation for severe lumbar 1 fracture in 2021 also suggested that the scope/degree of posterior superior wall fracture of vertebral body is also one of the risk factors for fixation failure [12]. The authors believe that the evaluation of vertebral posterior superior wall injury should be increased when evaluating thoracolumbar fractures.

3. Advantages of Schanz Pedicle Screw

The purpose of surgical treatment is to rebuild the stability of thoracolumbar vertebrae, restore the height of injured vertebrae as much as possible, and reduce postoperative deformity and complications. At present, there are many surgical methods such as anterior approach, posterior approach, and anterior–posterior approach, but there is no best scheme due to the complexity of fracture [13]. Short-segment (adjacent to upper and lower vertebrae) conventional pedicle screw fixation for A3/A4 [2] thoracolumbar burst fracture has been applied clinically, but the complication of screw rod rupture in severe fracture (LSC ≥ 7) restricts its popularization [14–16]. Previous studies have shown that many factors, such as the degree of primary injury of fracture, pedicle screw diameter, screw depth, screw type, and bone abnormality (such as osteoporosis), are the risk factors for the failure of conventional pedicle screw fixation [17–20]. The successful treatment of thoracolumbar burst fractures with adjacent to upper and lower vertebrae Schanz screw fixation by the authors and Aono et al. shows that Schanz screws have better ability to maintain the stability of fixation segments [8, 17].

In 2018, the author put forward for the first time that Schanz screw is successful in treating severe fracture (LSC ≥ 7), mainly because Schanz screw is more similar to the posterior column structure of spine and its stress conduction than conventional nail [8]. The posterior column structure of normal lumbar spine (upper and lower articular processes, isthmus and lamina) is similar to "butterfly shape." The structure of Schanz screw rod is similar to "][" shape, while that of conventional pedicle screw rod is similar to "| |" shape[8]. The stress of normal posterior column of spine is transmitted through butterfly-like posterior column. The stress conduction of Schanz screw is from outside to inside, then down and finally to outside downward(like ']['shape), and its connecting rod is located on both sides of spinous process and directly behind lamina[8, 19]. The stress of conventional pedicle screw is linear-like conduction, and its screw rods are located in the plane of upper and lower articular processes (see **Figure 1**) [8, 19].

Normal stress conduction between adjacent posterior columns (indirect conduction through intervertebral facet joint): from superior articular process along isthmus through lamina to inferior articular process and finally through intervertebral facet joint (indirect conduction) to superior articular process of the next vertebra. Stress conduction between Schanz screws and rods (indirect conduction through connecting clips): from upper screws to upper connecting clips (similar to isthmus), along connecting rods, through lower connecting clips (similar to intervertebral facet joints) and finally to lower screws. Direct conduction of stress between conventional screws and rods: from the upper screw to the lower screw directly through the connecting rod. Moderate fracture (LSC < 7) had no significant effect on the stress of screw and rod because the injured vertebra could still bear part of the load. In severe burst fracture (LSC ≥ 7), when the loads of the anterior, middle, and posterior column are all (/most) transmitted across the injured vertebra through the posterior screw and moderate rod, this direct transmission may lead to excessive stress concentration in a certain part of the screw or rod (often at the root of the screw) and fatigue break. This view is first proposed by the author.

Because the connection clip has the adjustment function [8], there is no need to bend the connection rod to keep the Schanz screw-rod tightly combined. However, conventional screws often need to bend the connecting rod to ensure the tight combination of screw and rod [16]. The ability of conducting stress of straight rod is

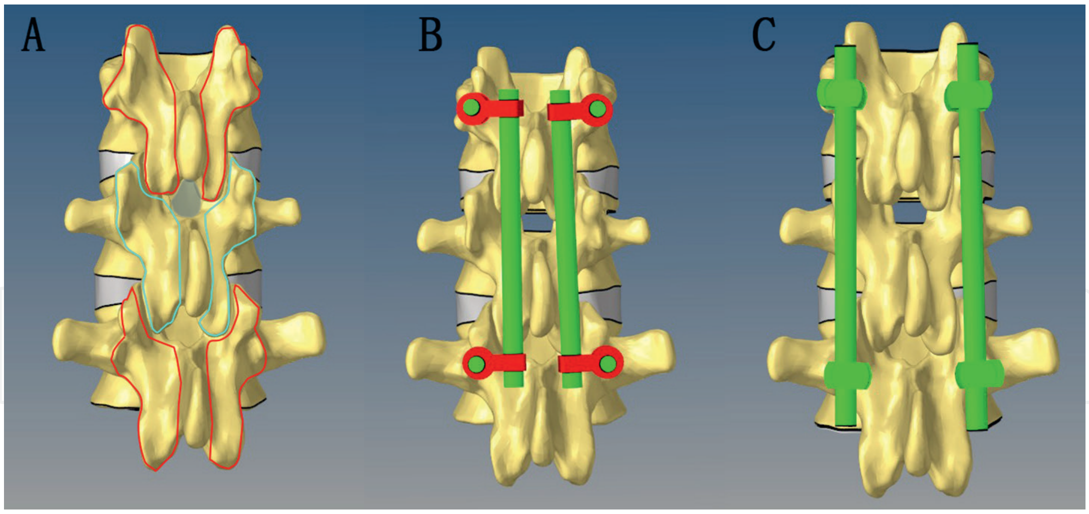

Figure 1.
Finite element simulation of posterior–anterior position of thoracic 12, lumbar 1, and lumbar 2 vertebrae. 1A. Normal T12, L1, and L2 butterfly-shaped rear column simulation diagram; 1B. T12 and lumbar 2Schanz pedicle screw fixation simulation diagram, Schanz screw rod is"][" shape, and its connecting rod is located on both sides of spinous process. 1C. Simulated images of routine pedicle screw fixation in T12 and L2. The structure of conventional pedicle screw rod is similar to "||"shape, and its connecting rod is located in the plane of intervertebral facet joint outside the lamina.

better than that of bent rod. Compared with conventional screw, the straight rods of Schanz screw are located on both sides of spinous processes, while the curved rods of conventional screws are located on the planes of upper and lower articular processes, so the ability of Schanz screw to limit excessive flexion and extension of fixed segments is stronger than that of conventional screw. Namely, the straight rod of Schanz screw can also play a certain function similar to PLC [8]. The authors' previous finite element studies suggest that the anterior flexion of fixation segments is also one of the risk factors for the failure of pedicle screw fixation [12, 19]. Pedicle screws maintain the stability of fixed segments by bearing loads and conducting stresses. Compared with conventional screws, Schanz screws have better stress conduction and stronger unloading capacity, so that the screw can maintain the stability of the fixed segment without obvious stress increase (not exceeding the fatigue threshold of the screw) [8, 12, 19].

4. Mechanism and advantage of traction reduction of oblique downward screw

The typical imaging features of burst fracture are compression of anterior column, comminution of upper endplate, burst fracture fragments of middle column retropulsed into spinal canal [1]. When the burst vertebral body is compressed more than 30%, most of the burst bone fragments collapse and move backward and are mainly located in the middle and posterior part of the vertebral body and in the spinal canal (bone defects are often seen in the anterior part of the vertebral body). Only after the bone fragments located in the middle and posterior part of the vertebral body are reduced forward and upward can the intraspinal canal bone fragments have the space and possibility of reduction [8]. Unlike the backward and upward traction force of the screw parallel to the upper endplate, the traction force of the screw oblique downward is forward and upward (see **Figure 2**) [8].

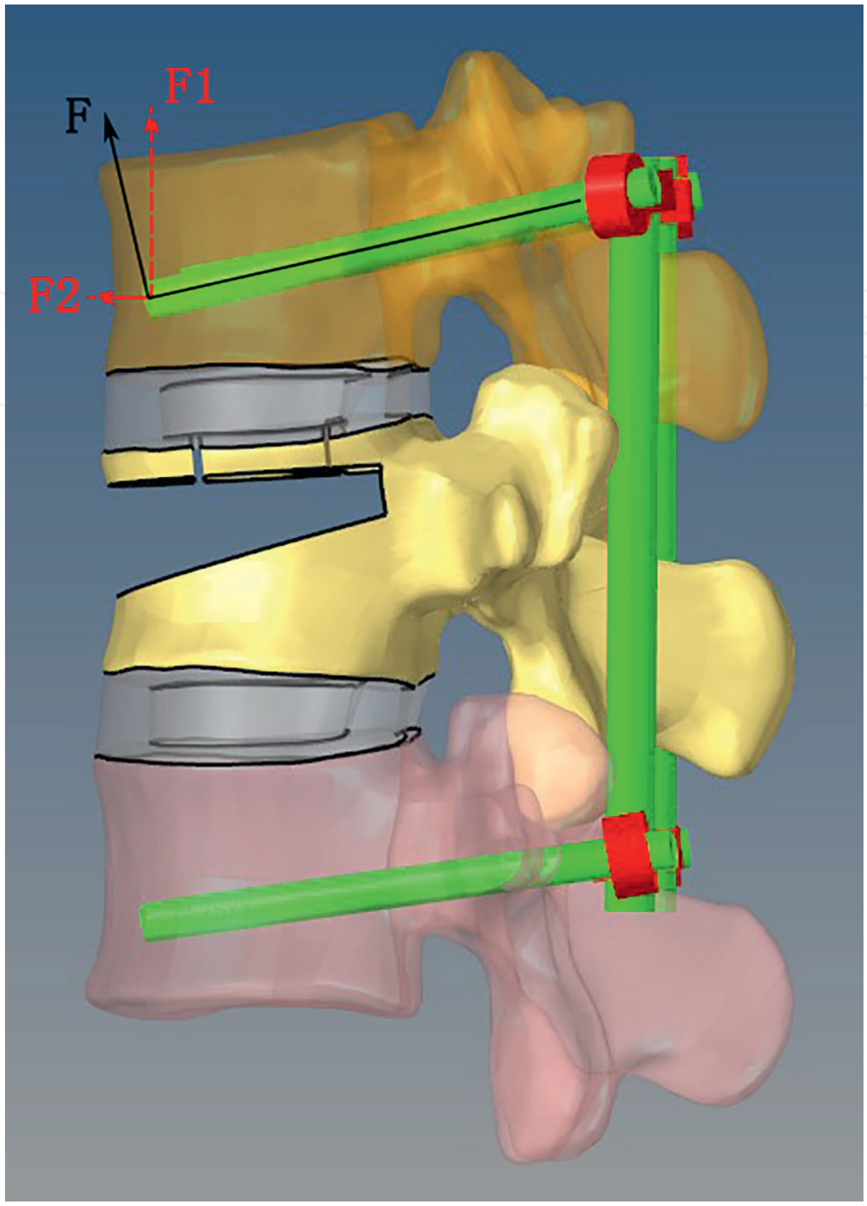

Figure 2.
Lateral finite element simulation of T12 and L2 Schanz pedicle screw oblique downward fixation of L1 severe burst fracture (LSC 9). The reduction traction F of the obliquely downward implanted screw in T12 includes an upward component F1 and a forward component F2.

In posterior column traction reduction, the forward and upward traction of the upper screw can not only elevate the height of vertebral body, but also move the bone fragments at the back of the vertebral body (in front of the spinal canal) forward and upward, providing enough reduction space for the bone fragments in the spinal canal to return [8] . Compared with the upward and backward traction of the conventional method, the forward and upward traction of the new method is more beneficial to the reduction of the intraspinal canal bone fragments and has less influence on the compressed dura sac and nerve [8]. In anterior column distraction reduction, the traction of upper screw is first forward and upward, then (beyond the level of upper endplate) backward and upward [8]. The forward and upward traction can make the collapsed and backward bones fragments move upward and forward. Upward and backward traction not only makes the bone fragments continue to be restored upward, but also makes the bone fragments displaced forward and downward return upward and backward [8]. The author's research based on his finite element model of burst fracture shows that it is safe to implant pedicle screw oblique downward within 15 degrees [19, 21].

5. Skills of oblique downward screw implantation and reduction

Due to limited space, the anesthesia, position and incision of this new method are detailed in the relevant paper published by the author in 2018 [8]. In this section, the authors focus only on the techniques of exposure of the operative area, oblique downward screw placement, and reduction (taking T12 and L2 Schanz pedicle screw fixation for lumbar 1 burst fracture as examples). Precautions for surgical site exposure: 1) subperiosteal dissection without transection of paravertebral muscles. The muscles at the attachment points of T12 transverse process and L2 superior articular process were turned upward and outward to expose intervertebral facet joints, so as to avoid damage to local intervertebral facet joints and joint capsule as much as possible; 2) avoid damage to supraspinous ligament and interspinous ligament; 3) only the paravertebral muscles of L1 need to be stripped to the extent that the connecting rod can be inserted; the lateral half of L1 lamina and T12L1 intervertebral facet joint need not be exposed.

Precautions for pedicle screw insertion: 1) Refer to the Roy-Camille method to select the nail entry point. 2) The parallel line of the upper endplate was the 0 degree reference line, and the pedicle screw was inserted into the middle and lower third of the vertebral body under the assistance of fluoroscopy (the angle between the long axis of the pedicle nail and the parallel line of the upper endplate was about 10°, not more than 15°). 3) According to the author's clinical experience, the sagittal position of the upper and lower screws should be as parallel as possible to achieve better reduction (based on the principle of force and reaction force). 4) The screw placement depth reaches 90% ~ 100% of the vertebral body. 5) Cyclic reduction was performed according to the sequence of posterior, anterior, and posterior column reduction: (1) during posterior column traction, the side with severe spinal stenosis was first reduced, and then the contralateral side was reduced. (2)Intraoperative lateral fluoroscopy is often difficult to directly observe the reduction of intraspinal fractures. The experience of the authors suggests that the angle change between the extension line of the upper endplate of the injured vertebral body and the extension line of the upper edge of the fracture fragment can indirectly judge whether the intraspinal canal fracture fragment is reduced or not. With the recovery of the height of the injured vertebral body, the angle between the two gradually decreased, indicating the reduction of the bone fragment, and the angle between the two was close to 0, indicating that the reduction was good. (3) The height of the anterior and posterior margins of the upper and lower intervertebral spaces of the injured vertebral body was similar to the height of the adjacent intervertebral discs, indicating that the anterior column was well reduced.

6. Indications and contraindications

The indications and contraindications of the new method are basically the same as those of the conventional screw. The author mainly discusses the characteristics of Schanz screw. Because the damage of Schanz pedicle screw to soft tissue is greater than that of percutaneous pedicle screw, the authors suggest using short-segment conventional percutaneous pedicle screw fixation for moderate fracture (LSC4–6) [5, 22, 23]. However, it is recommended to consider this new method when the fracture fragments retropulsed into the spinal canal seriously and requires lamina decompression. Indications of this new method are: (1) A3/A4 fracture [2, 3] with incomplete spinal cord/nerve injury with LSC ≥ 7 (fracture block protruding into spinal canal >40–50%); 2) fracture within 10 days; (3) MRI showed that the continuity of posterior longitudinal ligament (PLL) at the injured spinal canal level existed/did not break. Contraindications [2, 3]: 1) MRI showed that the PLL at the injured spinal canal level was broken, combined with cerebrospinal fluid leakage and/or complete paralysis (nerve injury); 2) unilateral pedicle fracture ≥90% or bilateral pedicle fracture ≥70%. 3) fracture with dislocation or C-type burst fracture [2, 3]; 4) congenital spinal malformation /severe degenerative scoliosis; 5) patients with severe osteoporosis (bone mineral density, BMD < −3.5); 5) Infectious/pathological fractures.

7. Thoracolumbosacral orthosis (TLSO)

The author's series of studies on the treatment of thoracolumbar fractures with short-segment pedicle screw fixation since 2018 showed that [8, 12, 18, 19, 21]: the maximum stress of pedicle screws increased with the aggravation of fracture degree, and the increase of screw stress in forward flexion was the most obvious. In moderate thoracolumbar fracture (LSC score 4–6), the risk of screw breakage is low with both types of screws, so brace assistance is not required. In severe fracture flexion, the fracture risk of conventional screws is increased while that of Schanz screws is low.

The maximum stress of these two screws in the upright position of severe fracture did not exceed the screw fatigue threshold, so the risk of fixation failure was low. In brief, maintaining an upright thoracolumbar position during early postoperative walking (within 3 months) reduces the risk of Schanz and conventional screw fixation failure. Although Schanz screws have a better ability to conduct stress compared with conventional screws, the authors' study [12, 19] showed that the bone defect area of the vertebral body after reduction of severe fractures has a slight movement during anterior flexion, and this micro movement is more severe in Schanz screws than in conventional screws. This slight movement may be one of the reasons for the re-collapse of the injured vertebra after Schanz screw fixation [8, 19, 24]. TLSO braces can keep the thoracolumbar and lumbar vertebrae upright, thereby reducing the micro movement of the injured vertebrae bone defect area and avoiding the re-injury of PLC and intervertebral disc caused by flexion and extension activities [24–26]. Early functional exercise (within 3 months) after short-segment pedicle screw fixation for severe thoracolumbar fractures requires TLSO assistance [8, 12, 19].The time of wearing TLSO was adjusted according to the size of bone defect area and the growth of new bone during follow-up.

8. Typical case

A 45-year-old male patient. L2 burst fracture with incomplete nerve injury (Frankel C grade). Schanz pedicle screw was implanted obliquely downward in adjacent upper and lower vertebrae and then directly distracted reduction and fixation was performed. Lamina decompression and bone grafting were not performed. The

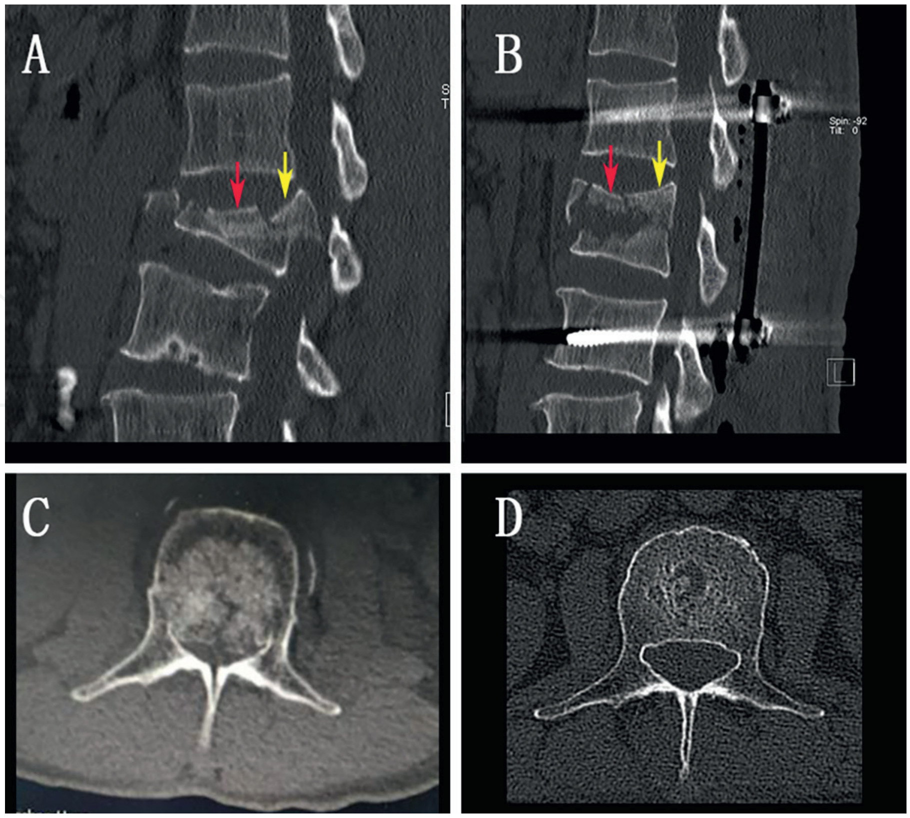

Figure 3.
3A preoperative sagittal CT image: Anterior column of L2 is compressed 80%, the middle column is comminuted, and the bone fragments enter the spinal canal ≥80%. The fracture fragment indicated by the red arrow shifts backward and downward, and the fracture fragment indicated by the yellow arrow obviously protrudes backward into the spinal canal; 3B. Sagittal CT image after L 1 and 3 Schanz pedicle screws oblique downward implantation and distraction reduction: Schanz pedicle screws were implanted obliquely downward in L1 and L3. The height of anterior and posterior edges of L2 vertebral body recovered to 90%, and the fracture fragments protruding into vertebral canal were basically reduced (the fracture blocks indicated by yellow and red arrows were reduced forward and upward), and there was a bone defect area in the anterior and middle part of the injured vertebral body. The kyphosis of injured vertebra was basically corrected, and the stenosis of spinal canal was obviously improved. 3C. Preoperative CT axial position showed that the vertebral body burst, the fracture fragments obviously protruded into the spinal canal, the spinal canal obviously narrowed, and the pedicle fracture. 3D. Axial CT images after fracture healing and internal fixation: The spinal canal is basically normal, and there is a small bone defect area in the middle of L2 vertebral body.

neurological function was Frankel D 3 days after operation and Frankel E 1 month after operation (see **Figure 3**).

9. Conclusion

Compared with the previous pedicle screw fixation parallel to the end plate, the oblique downward Schanz pedicle screw can direct reduce the intraspinal fracture fragments without lamina decompression and does not increase the risk of nerve injury. This is a new safe and effective method for reduction of intraspinal fracture fragments. The treatment of severe thoracolumbar burst fracture with short-segment Schanz pedicle screw oblique downward fixation requires TLSO brace to help prevent the injured vertebra from re-collapse in the early stage after operation.

Appendix

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