

Effects of Endplate Healing Morphology on Intervertebral Disc Degeneration after Pedicle Screw Fixation for Thoracolumbar Fractures

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Abstract

Background: The cartilage endplate plays an important role in the stress distribution and nutrition metabolism of intervertebral disc. The healing morphology of the endplate after spinal fracture and its effect on the intervertebral disc degeneration are still unclear.

Methods: 51 patients with single-level thoracolumbar fractures underwent posterior open reduction and pedicle screw fixation. Combined with the initial CT and MRI images, the endplate injury was defined as three types, which are unilateral endplate injury, bilateral endplate injury and no endplate injury. According to the location of the injury in the endplate, it was further divided into endplate central injury and endplate peripheral injury. The degree of post-traumatic disc lesions and disc degeneration during follow-up were classified based on the Sander classification and the Pfirrmann classification, respectively. According to the T1 image of MRI in the final follow-up, the healing morphology of endplates was classified into three types including the increased endplate curvature, the irregular healing and the traumatic Schmorl nodes.

Results: Cartilage endplate fractures are closely related to the degree of degeneration of the intervertebral disc ($P=0.003$). Injuries in different parts of the endplate have no significant effect on the intervertebral disc degeneration ($P=0.204$). The healing morphology after endplate fracture significantly affected the degree of intervertebral disc degeneration ($P=0.001$). The comparison of groups showed that the effects of irregular healing and traumatic Schmorl nodes on disc degeneration were not statistically different, but were significantly different from those with increased curvature.

Conclusions: Increased endplate curvature, irregular healing and traumatic Schmorl nodes are three common forms of healing. The irregular healing and the traumatic Schmorl nodes are closely related to intervertebral disc degeneration. The existence and severity of the endplate injury can provide valuable information for individualized clinical decision-making processes.

Background

With the development of pedicle screw technology, most patients with spinal fractures have achieved good results with surgery. However, some patients have chronic instability and low back pain after surgery, with severe disc degeneration, which seriously affects quality of life [1-3]. The intervertebral disc plays an important role in maintaining the stress distribution of the spine. Because of its elastic biomechanical characteristics, intervertebral discs can absorb energy and exert a moderating influence to make the stress distribution more uniform during stress transmission. Therefore, before a vertebral fracture occurs, the intervertebral disc has absorbed a large amount of energy, and injury to the intervertebral disc is inevitable [4]. Due to the three-dimensional complexity of injuries, the imaging manifestations of intervertebral disc injuries are also complicated, making it difficult to describe the degree of injury with a standard and widely recognized evaluation system. Sander et al. reported a new evaluation system for traumatic intervertebral disc lesions based on the morphological and signal changes of injured intervertebral discs. The evaluation method is simple and has been widely used in

clinical practice. However, this approach does not describe the clinical outcome of the injured intervertebral disc and fails to clarify the relationship between each injury type and intervertebral disc degeneration [5].

As a part of the intervertebral disc, the cartilage endplate plays an important role in facilitating the nutrition supply, metabolic exchange and biomechanical transmission of the whole intervertebral disc. If the structure or composition of the cartilage endplate changes, it will affect the infiltration and exudation of nutrients and metabolic waste, which then affect the metabolism of intervertebral disc cells and promote the degeneration of intervertebral disc tissue. Although the bony part of a vertebral fracture can be completely healed and restored to normal strength, the pedicle screw system cannot directly reduce the endplate fracture, which makes the healing morphology of the cartilage endplate unpredictable, and the relationship between the healing morphology and intervertebral disc degeneration is not very clear. We hypothesized that cartilage endplate injury would accelerate the degeneration of the intervertebral disc and explored the relationship between the healing morphology of the cartilage endplate and intervertebral disc degeneration by follow-up magnetic resonance imaging (MRI).

Materials And Methods

Experimental design

Prior to this retrospective study, we gained approval from the institutional review committee. We reviewed the medical records of 51 patients with traumatic single-level thoracolumbar fractures treated in the orthopedic trauma service center from June 2011 to May 2019. An electronic medical records system was used to review the injury mechanisms. This study only included T11 to L4 thoracolumbar fractures. The exclusion criteria included pathological spinal fracture, spondylitis, osteoporotic fracture (age over 60 years or T value of dual X-ray bone mineral density (BMD) measurement less than 2.5), and degenerative disc disease without injury to the intervertebral disc.

Imaging

All patients underwent standard X-ray (including anteroposterior view and lateral view), computed tomography (CT) and MRI preoperatively. According to the severity of the fracture and the surgeon's preference and proficiency, the operation type was divided into open reduction and short segment fixation, open reduction and intermediate pedicle screw techniques, and open reduction and long segment fixation. In all surgeries, no bone graft fusion was performed between the transverse process or spinous process, and no transpedicular bone grafting was performed. The mean time until the internal fixator was removed was 13.5 months after the injury (range: 8-18 months). The average total follow-up time was 28.2 months (range, 11-66 months). MRI data were obtained by using a 3.0T MAGNETOM Verio, 1.5T MAGNETOM Avanto, or 1.5T MAGNETOM Symphony MRI system (Germany, Siemens) with a spine surface matrix coil (Spine Matrix) and turbo spin echo imaging (TSE). T2-weighted images were obtained in the axial plane. In the supine position, images were obtained with T1, T2 and T2 inversion recovery fat-saturated sequences (TIRMs) in the sagittal plane. Sagittal T1-weighted imaging (T1WI) and T2-weighted

imaging (T2WI) was performed with field of view (FOV) of 280 mm/300 mm, a matrix of 288 * 384, 256 * 512, or 224 * 320, and a layer thickness of 4 mm. Sagittal T2WI with TIRM was performed with an FOV of 280 mm/300 mm, matrix of 230 * 256, 192 * 256, or 192 * 320, and a layer thickness of 4 mm. Axial T2WI was performed with an FOV of 210-240 mm, matrix of 240 * 320, 288 * 384, or 204 * 512, and a layer thickness or 4 mm. The following sagittal MRI sequences were performed: T1WI TSE (repetition time/echo time (TR/TE), 540-650/9.6-11), T2WI TSE (TR/TE, 1650-3000/88-101), T2WI TIRM (TR/TE, 2560-4000/70-80), axial T2WI TSE (TR/TE, 2300-3800/99-112).

Data analysis

According to the AO classification, the fracture patterns were classified on the initial X-ray and CT images as follows: Type A, vertebral compression; Type A1, simple compression fracture without involving the posterior wall of the vertebral body; Type A2, coronal splitting fracture of the bilateral endplates without involving the posterior wall of the vertebral body; type A3, burst fracture involving the posterior wall of the vertebral body; Type B, tension band injury; and Type C, displacement/translational injury. Based on the initial CT and MRI scans, the endplate injury was classified according to whether the cartilage endplate was fractured and was defined as a unilateral endplate injury, bilateral endplate injury or no endplate injury; the endplate fracture group was further divided into the central endplate injury and peripheral endplate injury groups according to the injury site. On the median sagittal and median coronal images, the endplate was divided into three equal parts [6]. If the most obvious area of the endplate fracture showing angulation was located in the middle third portion, it was defined as a central endplate injury (equivalent to the nucleus pulposus in the disc), and an injury of circumjacent third was defined as a peripheral endplate injury (equivalent to the annulus fibrosus in the disc). According to Sander's classification of traumatic intervertebral disc lesions, the intervertebral disc injuries were classified based on the preoperative MRI [7]. A grade 0 injury showed no morphological change in the intervertebral disc of the fractured vertebral body, and it was considered that there was no injury. The manifestation of a grade 1 injury was high signal on T2-weighted or T2 TIRM images, suggesting disc edema. A grade 2 injury was defined as a reduction in the original hyperintensity around the lesion on T2-weighted or T2 TIRM images and the appearance of isointensity to hyperintensity on T1-weighted images, indicating disc rupture with intradiscal hemorrhage. The criteria for grade 3 injury were intervertebral disc invasion, annular tear or endplate protrusion. According to the Pfirrmann classification system, the degree of intervertebral disc degeneration was evaluated on MRI at the final follow-up. The cranial and caudal discs of fracture were compared with uninjured discs to take into account age-related changes in disc signal intensity.

According to the median sagittal T1-weighted MRI scans, the healing morphology of the endplate was divided into increased endplate curvature (IEC), irregular healing (IH) and traumatic Schmorl node (TSN). Specifically, a straight line was drawn along the median sagittal image of the endplate on the anterior and posterior edges of the vertebral body. If there was intervertebral disc tissue between the straight line and the edge of the endplate, and compared with the adjacent endplate without fracture, the indentation degree was increased, then there was IEC (Figure 1A). If the signal of the cartilage endplate was continuous, but the signal pattern was not smooth, and there were local bumps or indentations, then there was IH (Figure 1B). If the signal of the cartilage endplate was continuous, and there was a round or

irregular herniation through the cartilage endplate, in which the intervertebral disc tissue can be seen and intruded, then there was TSN (Figure 1C).

Data analysis was performed by an experienced traumatic orthopedic surgeon and a senior radiologist experienced in musculoskeletal imaging. Three months after the first assessment, the traumatic orthopedic surgeon and radiologist re-evaluated all data in the same way at their own independent workstations. IBM SPSS 21.0 (IBM corporation, Armonk, New York, USA) was used for statistical analysis. The Wilcoxon rank sum test and Kruskal-Wallis H test were used to statistically analyze the grading data. The least significant difference (LSD) test was used for pairwise comparisons. A $P < 0.05$ was considered statistically significant.

Results

Patient characteristics

A total of 51 patients were enrolled in this study, including 39 males and 12 females. The average age was 42.19 years (range, 22-59 years). Fall injuries accounted for 47.2% (24/51) of the 51 cases, followed by heavy objects 25.4% (13/51), fall from height 17.6% (9/51), and traffic accidents 9.8% (5/51). Among them, 23 patients were treated with open reduction and short segment fixation, 16 patients were treated with open reduction and intermediate pedicle screw techniques, and 12 patients were treated with open reduction and long segment fixation.

Analysis of the disc degeneration by fracture patterns

Regarding the injured spinal segment, we found 7.8% of the injuries at T11, 23.5% at T12, 45.4% at L1, 17.6% at L2, 1.9% at L3, and 3.8% at L4. Regarding the type of fracture, the distribution was as follows: 31.1% (16/51) were type A1 fractures, 5.8% (3/51) were type A2 fractures, 37.7% (19/51) were type A3 fractures, 23.5% (12/51) were type B fractures, and 1.9% (1/51) were type C fractures. As the fracture severity increased, the degree of intervertebral disc degeneration obviously increased ($P = 0.006$) (Table 1). Among the groups, the degree of disc degeneration of A1 fractures was significantly different from that of other types of fractures and was significantly lower than that of other fracture types (A1 vs. A2 $P=0.012$, A1 vs. A3 $P=0.003$, A1 vs. B $P=0.001$).

Analysis of disc degeneration according to endplate lesion

Among the 51 patients included, 33 patients had a unilateral endplate injury, and the corresponding 33 intervertebral discs were enrolled in the study; 15 patients had bilateral endplate injuries, and the corresponding 30 intervertebral discs were enrolled. In 3 patients with no endplate injuries, the corresponding 6 intervertebral discs were included as a control group. The existence of an endplate injury was closely related to the degree of intervertebral disc degeneration ($P = 0.003$) (Table 2). There was no significant difference in the degree of intervertebral disc degeneration between unilateral endplate injury

and bilateral endplate injury (unilateral vs. bilateral $P = 0.075$, unilateral vs. no injury $P = 0.010$, bilateral vs. no injury $P = 0.001$).

Analysis of disk degeneration according to endplate lesion site

Among the 51 patients included, 33 patients had a unilateral endplate injury, and 15 patients had bilateral endplate injuries. A total of 63 endplates were included as samples, of which 65.1% (41/63) were damaged in the central area of the endplate, and 34.9% (41/63) were damaged in the peripheral area of the endplate. There was no significant difference in the degeneration of intervertebral discs according to the site of endplate injury ($P = 0.204$) (Table 3).

Analysis of disk degeneration according to intervertebral disc lesion

Of the 51 patients included, a total of 102 intervertebral discs were included as the research object, and intervertebral disc lesions were graded based on the preoperative original MRI; grade 0 accounted for 23.5% (24/102) of the lesions, grade 1 accounted for 37.4% (38/102), grade 2 accounted for 26.4% (27/102), and grade 3 accounted for 12.7% (13/102). The more serious the injury to the intervertebral disc was, the more obvious the degeneration of the intervertebral disc during the final follow-up. The classification system for traumatic disc lesions can predict the degree of degeneration to a certain extent, and there was a significant association ($P < 0.001$) (Table 4).

Analysis of disk degeneration according to endplate healing morphology

Based on the MRI scans at the last follow-up, 63 cases of cartilage endplate fractures healed, and the healing morphology was as follows: the IEC was found in 33.3% (21/63) of the cases, IH was found in 42.9% (27/63), and TSNs were found in 23.8% (15/63). The healing morphology after an endplate fracture significantly affected the degree of intervertebral disc degeneration, and the correlation was statistically significant ($P=0.001$) (Table 5). A comparison among the groups found that there was no significant difference between IH and TSN in intervertebral disc degeneration (IH vs. TSN $P=0.356$). Compared with the other two groups, the IEC group had significantly different intervertebral disc degeneration (IEC vs. IH $P<0.001$, IEC vs. TSN $P=0.014$).

Discussion

The intervertebral disc is composed of three different components: a central gelatinous nucleus pulposus, fibrous collagen ring and cartilage endplate. The endplate is a layered composite material composed of semiporous thickened cancellous bone (0.6-1 mm) and transparent cartilage (0.2-0.8 mm) [8]. Because of its unique anatomical morphology and material properties, the cartilage endplate has two important functions: biological transport and stress conduction [9]. On the one hand, the intervertebral disc is the largest avascular structure in the human body, and the nucleus pulposus cells almost completely depend on the nutrients provided by the capillary bed of the vertebral body near the endplate. Once the nutrients reach the endplate of the cartilage, the smaller solutes (glucose, lactic acid, sulfate, and oxygen) reach

the intervertebral disc cells mainly by diffusion, while the larger solutes need to enter the nucleus pulposus by convection. On the other hand, the endplate serves as a hard/soft tissue interface between the intervertebral disc and the vertebral body and transmits complex multiaxial loads between the intervertebral disc and the vertebral body to ensure a proper range of motion. The endplate evenly distributes the stress in these discs to the surface of the adjacent vertebrae and prevents the compressed nucleus pulposus from protruding into the lower trabecular bone.

The destruction of the integrity of the endplate may cause a pathological cascade, eventually leading to degeneration of the adjacent intervertebral disc. First, the protrusion of the nucleus pulposus into the vertebral body leads to a direct loss of water and proteoglycans in the nucleus pulposus, leading to intervertebral disc degeneration. The accompanying inflammatory reaction and autoimmune reaction can further destroy the homeostasis of the intervertebral disc and damage cell metabolism [10]. Second, endplate damage and the accompanying repair reaction may destroy or block the contact channel between the intervertebral disc tissue and the bone marrow in the vertebral body, hindering the nutritional supply of the intervertebral disc. Due to nutrient deprivation (mainly oxygen and glucose) and the accumulation of metabolic waste products (mainly lactic acid), impaired solute transport is thought to be the cause of nucleus pulposus cell death and disc degeneration [11]. In addition, endplate injury changes the matrix stress distribution near the intervertebral disc, which may further hinder the metabolism of intervertebral disc cells and lead to progressive degeneration of the intervertebral disc [12]. A study was conducted by directly measuring the morphological characteristics of 600 cadaveric lumbar endplates and evaluating intervertebral disc degeneration by discography [13]. It was found that endplate injury was closely related to the degeneration of the intervertebral disc, and the morphology of the endplate played a particularly important role in the pathogenesis of intervertebral disc degeneration. In addition to the scarce blood supply at the periphery of the annulus fibrosus, the vast majority of the entire intervertebral disc still relies on cartilage endplates for nutrient and metabolic exchange. These studies also support our finding that traumatic endplate injury can lead to disc degeneration, regardless of whether the endplate injury is unilateral or bilateral.

The factors leading to intervertebral disc degeneration are complex, usually involving the synergistic effect of physical and biological mechanisms. According to the morphological characteristics of the endplate, the endplate near the annulus fibrosus is thicker than that in the central nucleus pulposus region, and the lower endplate of the same vertebral body is thicker than the upper endplate [8]. We observed that the central nucleus pulposus area is the main area involved in endplate fracture. However, due to the different mechanisms of injury and the three-dimensional complexity of the injury, the fracture lines have various patterns, such as a stellate-shaped radial pattern, step-shaped line, and local protrusion-shaped line. Although the most distinct area of endplate fracture showing angulation is located in the central region of the endplate, the fracture line often extends to the peripheral region, and vice versa. In our study, there was no significant difference in the degeneration of the intervertebral discs among different endplate sites. The integrity of the endplate plays an important role in maintaining the stress distribution and nutrition supply of the intervertebral disc. Regardless of whether it occurs in the central or peripheral region, a slight fracture or defect of the endplate structure is enough to have an

important impact on the mechanical environment of the intervertebral disc. Endplate fracture leads to an abnormal stress distribution in the adjacent intervertebral discs and increases the risk of internal rupture and degeneration. When endplate fracture occurs and the integrity of the endplate is destroyed, the water content in the annulus fibrosus and the proteoglycan content in the nucleus pulposus are significantly reduced; moreover, the absence of cartilage increases the permeability of the endplate and promotes an inflammation reaction in the endplate, which in turn affects the ability of the endplate to transport nutrients to the intervertebral disc. In addition, in vitro studies have also found that endplate damage promotes a low expression of anabolic genes (aggrecan) and high expression of catabolic genes (MMP-1, -3, -13) and proinflammatory genes (TNF, IL-6) and speeds up the process of intervertebral disc degeneration [14]. The Magerl AO spinal fracture classification system contains a comprehensive description of the fracture anatomy and uses successive grades in a hierarchical system to represent increased fracture severity [15]. According to epidemiological studies, the morbidity of type A1 and A3 fractures is the highest and that of type C fractures is the lowest [16], which is also consistent with the distribution of fracture types in our study. As the severity of the fracture increases, the form of intervertebral disc injury can also manifest as intervertebral disc edema, intradisc hemorrhage, the nucleus pulposus protruding into the vertebral body, or even a complete tear. In our previous study, we also found that the severity of the injury to the adjacent intervertebral disc in thoracolumbar fractures was positively correlated with the type of Magerl AO fracture [17]. When the nucleus pulposus protrudes into the vertebral body, the volume of the intervertebral disc decreases, the height of the intervertebral space decreases, and the pressure in the vertebral body increases, which breaks the balance of the pressure difference between the subchondral bone and cartilage endplate and then affects the diffusion of nutrients to the intervertebral disc, leading to intervertebral disc degeneration.

Vaccaro et al. reported a new thoracolumbar injury classification and severity score system (TLICS) that includes neurological status and posterior ligamentous complex integrity [18]. The TLICS forces clinicians to consider other aspects of instability and severity. Although this is a step forward, this approach still does not consider information about the impact of the injury on the adjacent intervertebral disc, which has been shown to play a crucial role in post-traumatic stability and prognosis. In recognition of this omission, Sander et al. identified morphological and signal changes of the injured intervertebral disc by routine MRI and established a grading system. According to the signal of the intervertebral disc, the injuries can be divided into four types: grade 0 to grade 3. The interobserver and intraobserver reliability was analyzed by the Cohen kappa coefficient, and $\kappa=0.96$, which means that the system has a high degree of credibility [5]. Compared with radiology and CT, MRI plays a dispensable role in the classification system. However, the imaging capacity of MRI for soft tissue injury makes it increasingly useful in the diagnosis of thoracolumbar vertebral fractures, and this method plays an especially irreplaceable role in the imaging of intervertebral discs and cartilage endplates. Therefore, we used MRI to explore the relationship between the classification of traumatic intervertebral disc lesions and postoperative intervertebral disc degeneration. Sander himself was aware of this potential relationship. In his subsequent study, the classification system was used to compare the intervertebral disc injury after trauma and 1-year follow-up outcome. Among the enrolled 54 discs, more than 50% of the grade 0 discs

were rated as grade 2, while those with grade 3 injury did not improve at the final follow-up [19]. This study suggested that disc injury is progressive, especially for less severe discs with only signal changes but no morphological changes. For more severe grade 3 injuries, no repair of the intervertebral disc was observed during follow-up, and even obvious degeneration occurred. This is consistent with our current research conclusions that the more severe the intervertebral disc injury, the more obvious the disc degeneration at follow-up. This also proves that the traumatic disc lesion classification system can predict the degree of disc degeneration to a certain extent. The difference is that we paid more attention to the prognosis of intervertebral disc injuries. The Pfirrmann degeneration classification system was used instead of the traumatic disc lesion classification system in the follow-up. The average follow-up time was 28.2 months, up to 66 months.

The endplate is the mechanical interface between the vertebral body and the intervertebral disc. It not only absorbs a considerable amount of hydrostatic pressure due to the mechanical loading of the spine but also, together with the intervertebral disc, helps to distribute the stress evenly throughout the vertebral body. Therefore, the morphology of the endplate plays an important role in maintaining the above functions. In previous studies on the relationship between vertebral endplate morphology and lumbar disc degeneration, researchers found that the level of vertebral endplate flattening was related to the severity of intervertebral disc degeneration [20]. Pappou et al. analyzed the relationship between the morphology of the lumbar endplate and the degree of degeneration by MRI, and their research revealed that the shape of the endplate was related to disc degeneration and Modic changes [21]. The shape of the endplate changed from concave to flat to irregular, and the degree of degeneration of the lumbar intervertebral disc gradually increased. The changes in endplate morphology on radiology reflect the degree of disc degeneration to a certain extent. In our study, the degree of intervertebral disc degeneration corresponding to IEC was lower than that corresponding to IH and TSN, while there was no significant difference between IH and TSN. In all fractured vertebrae, there were no significant Modic changes in the MRI signal. The IEC seems to be a "protective mechanism" in the process of intervertebral disc degeneration. The IEC group usually showed a light simple fracture on the endplate. After distraction with pedicle screws, the endplate was reduced well, and the shape was flat. Wolff's law states that when the load on the bone changes, the bone tissue is remodeled to accommodate the load on the bone. The biomechanical study of the intervertebral disc showed that the stress transmitted by the intervertebral disc mainly converged on the center of the endplate when the intervertebral disc was normal. The stress not only affects the volume and shape of the intervertebral disc but also has effects on the endplate, especially the axial stress load, leading to a bending deformation of the endplate and trabecula under the endplate. Therefore, IEC may be the result of endplate remodeling to adapt to the changed stress distribution under axial stress. On the follow-up T1 MRI scans, we observed that the signal of the endplates with IH and TSN was continuous, so we considered these two kinds of healing forms as "malunion". These two types of healing were often seen in patients with obvious displacement of the endplate fracture. Pedicle screws can reduce the height of the vertebral body but cannot directly reduce the endplate, and there is annulus fibrosus attached to the endplate, preventing reduction. The reduction of the endplate was often unsatisfactory, which was directly due to healing of the endplate deformity. TSNs had two forms in our

observations. One was a grade 3 injury of the intervertebral disc. The nucleus pulposus broke into the vertebral body through the endplate. The endplate could not be reduced after surgery, so the nucleus pulposus tissue still remained in the vertebral body, and TSN formed after the endplate was healed. These TSNs were often irregular in shape in the endplate [22]. The other form was that the trauma only caused a slight fissure fracture of the endplate. Under repeated stress stimulations, the nucleus pulposus tissue gradually herniated into the vertebral body through the weak area of the endplate (Figure 2). The formation mechanism of these TSNs is similar to that of the degenerative Schmorl nodes. The shape of the endplate in the vertebral body was relatively smooth, approximately round or oval [23]. Williams et al found that Schmorl nodes were closely related to lumbar disc degeneration and low back pain, although these nodes were not independent predictors of low back pain [24]. In an epidemiological study of lumbar endplate injury, it was found that endplate irregularities were closely related to severe disc degeneration, and their risk ratio (RR) was as high as 16.09 for Pfirrmann grade IV or V degeneration [25].

One of the limitations of our study is the lack of clinical evaluation of disc degeneration corresponding to endplate injury. According to the existing literature reports, degenerative changes of the intervertebral disc do not necessarily appear to correspond to clinical symptoms, and the symptoms can occur for a few years or even more than 10 years [26]. However, the follow-up time in our study was relatively short, for an average of 28.2 months after fracture. Therefore, further studies should explore the relationship between the clinical symptoms of degenerative changes and the severity of disc injury in the long-term follow-up. The value of simple imaging changes without confirmed clinical relevance is limited. On the other hand, because this study is a retrospective analysis of patient imaging data, some inherent limitations are inevitable. This is a single-center study with a small sample size. We need to confirm our findings through a multicenter, prospective study with a large sample size. We are conducting further research to directly reduce the endplate through the transpedicular approach and to analyze whether endplate reduction can delay or improve disc degeneration. Clinicians should pay attention to any form of endplate injury to determine the best surgical strategy.

Conclusion

The normal anatomy and integrity of the endplate play an important role in providing biomechanical conduction, stress redistribution, and nutrition and metabolism in the intervertebral disc. Once an injury breaks the inherent balance within the endplate, the injury will cause or aggravate disc degeneration through a variety of pathways. After vertebral fracture, IEC, IH and TSN are common forms of healing. IH and TSN are closely related to intervertebral disc degeneration. The existence and severity of the endplate injury can provide valuable information for individualized clinical decision-making processes.

Declarations

Ethics approval and consent to participate

This study was approved by the Research and Ethics Committee of the Third Hospital of Hebei Medical University, and all patients gave written informed consent for their information to be stored in the database of this hospital and used for medical research.

Consent for publication

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

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

PCW conceptualized and designed the study, drafted the initial manuscript, and reviewed and revised the manuscript. YSS, DR and DHL designed the data collection instruments, collected data, carried out the initial analyses, and reviewed and revised the manuscript. JFL, TCW, WQ and YPW coordinated and supervised data collection, and critically reviewed the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Tables

Table 1 Comparisons of degree of disc degeneration according to the fracture classification.

Fracture Classification	Classification of disc degeneration during follow-up				χ^2	<i>P</i>
	I	II	III	IV		
A1	12 (37.5%)	13 (40.6%)	7 (21.9%)	0 (0.0%)	14.517	0.006
A2	0 (0.0%)	2 (33.3%)	4 (66.7%)	0 (0.0%)		
A3	3 (7.9%)	17 (44.7%)	18 (47.4%)	0 (0.0%)		
B	2 (8.3%)	9 (37.5%)	11 (45.9%)	2 (8.3%)		
C	1 (50.0%)	0 (0.0%)	1 (50.0%)	0 (0.0%)		

Table 2 Comparisons of degree of disc degeneration according to the endplate injury.

Endplate injury	Classification of disc degeneration during follow-up				χ^2	<i>P</i>
	0	1	2	3		
unilateral endplate injury	0 (0.0%)	20 (60.6%)	12 (36.4%)	1 (3.0%)	11.886	0.003
bilateral endplate injury	0 (0.0%)	11 (36.7%)	18 (60.0%)	1 (3.3%)		
no endplate injury	4 (66.6%)	1 (16.7%)	1 (16.7%)	0 (0.0%)		

Table 3 Comparisons of degree of disc degeneration according to the injury site of endplate.

Injury site of endplate	Classification of disc degeneration during follow-up			<i>Z</i>	<i>P</i>
	0	1	2		
central injury	13 (59.1%)	9 (40.9%)	0 (0.0%)	1.271	0.204
peripheral injury	18 (43.9%)	21 (51.2%)	2 (4.9%)		

Table 4 Comparisons of degree of disc degeneration according to the grade of intervertebral disc injuries.

Grade of intervertebral disc lesions	Classification of disc degeneration during follow-up				χ^2	<i>P</i>
	0	1	2	3		
0	16 (66.7%)	5 (20.8%)	3 (12.5%)	0 (0.0%)	41.131	<0.001
1	2 (5.3%)	25 (65.8%)	11 (28.9%)	0 (0.0%)		
2	0 (0.0%)	8 (29.6%)	17 (63.0%)	2 (7.4%)		
3	0 (0.0%)	3 (23.1%)	10 (76.9%)	0 (0.0%)		

Table 5 Comparisons of degree of disc degeneration according to the endplate healing morphology.

Endplate healing morphology	Classification of disc degeneration during follow-up			χ^2	<i>P</i>
	0	1	2		
IEC	17 [81.0%]	4 [19.0%]	0 [0.0%]	13.296	0.001
IH	8 [29.6%]	17 [63.0%]	2 [7.4%]		
TSN	6 [40.0%]	9 [60.0%]	0 [0.0%]		

IEC - increased endplate curvature; IH - irregular healing; TSN - traumatic Schmorl node.

Figures



Figure 1

Increased endplate curvature (A), irregular healing (B), and traumatic Schmorl nodes (C) images on T1-weighted magnetic resonance images. Landmarks in midsagittal plane: the white straight line represents the connecting line between the anterior and posterior edges of the vertebral body. The white arrow represents traumatic Schmorl node formation due to unsatisfactory reduction of the endplate.

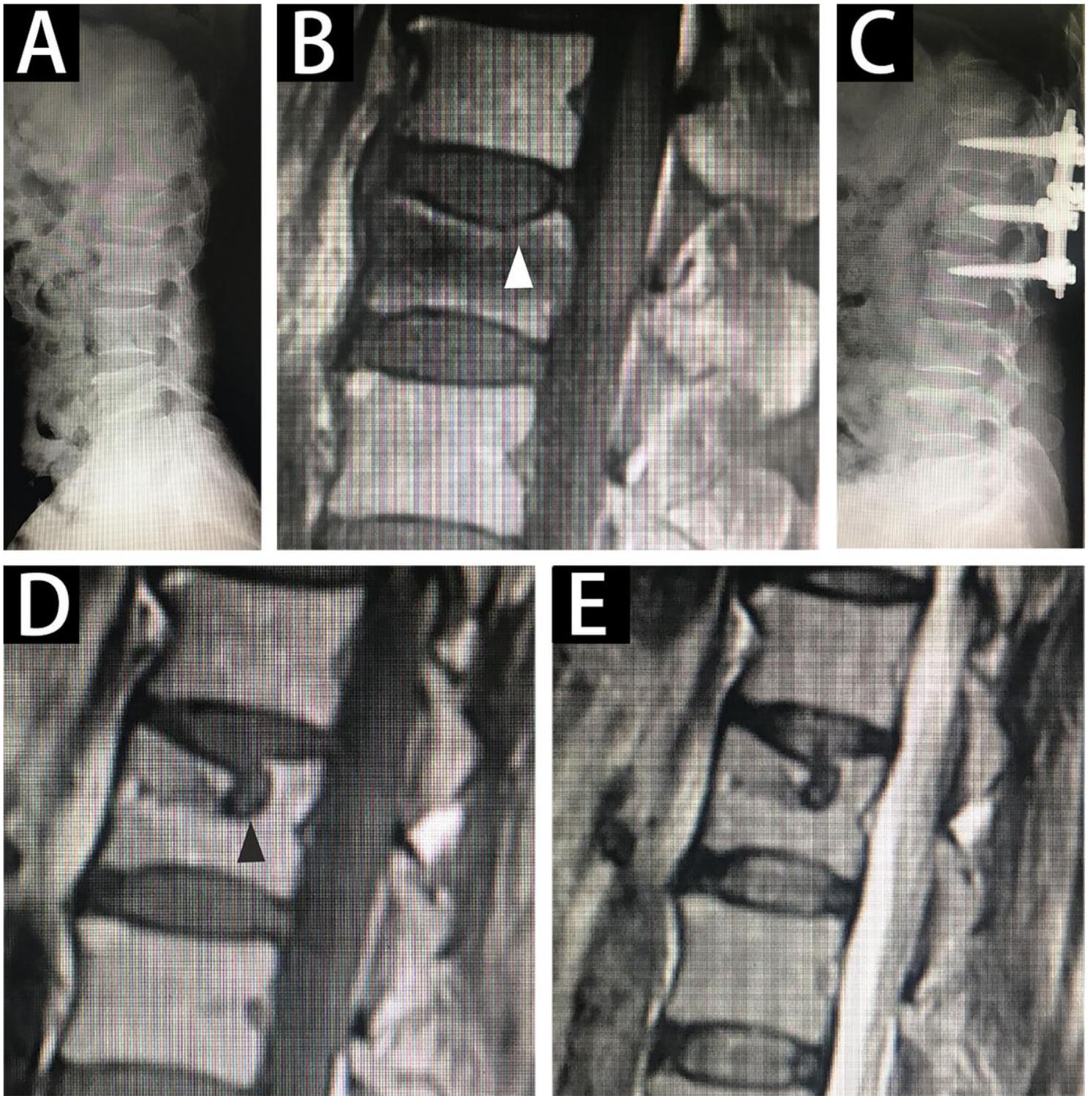


Figure 2

(A) the lateral view of a 59-year-old man with a L1 vertebral fracture due to the fall injury. (B) the preoperative image on T1-weighted image. The white arrow represents a slight fissure fracture of the upper endplate. (C) the postoperative image with open reduction and intermediate pedicle screw in lateral view. (D) the follow-up image on T1-weighted image. The black arrow represents traumatic Schmorl node formation with a smooth and round outline. (E) the follow-up image on T2-weighted image. The upper intervertebral disc was classified as Grade 4 by Pfirmann degeneration classification.

Supplementary Files

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