Reliability and application of the new morphological classification system for chronic symptomatic osteoporotic thoracolumbar fracture

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Abstract

Objective

This study proposed a new classification system for Chronic Symptomatic Osteoporotic Thoracolumbar Fracture (CSOTF) based on fracture morphology. Research on CSOTF has increased in recent years. However, the lack of a standard classification system has resulted in inconveniences regarding communication, research and treatment. Previous studies of CSOTF classification exhibit different defects, and none of these studies are widely accepted.

Methods

We collected 368 cases of CSOTF in our hospital from January 2010 to June 2017 and systematically analyzed the imaging data of all patients to develop a classification system. Imaging examinations included dynamic radiography, computed tomography scans and magnetic resonance imaging. Ten investigators systematically studied and fully understood the classification system grading 40 cases on two occasions, examined 1 month apart. Kappa coefficients (κ) were calculated to determine intraobserver and interobserver reliability.

Results

The new classification system for CSOTF was divided into types I-V according to whether the CSOTF exhibited dynamic instability, spinal stenosis or kyphosis deformity. Intra- and interobserver reliability were excellent for all types ($\kappa = 0.83$ and 0.85, respectively).

Conclusions

The new classification system for CSOTF demonstrated excellent reliability in this initial assessment. The system is convenient for communication and research, but wide clinical application are needed to confirm its effectiveness and guide clinical treatment.

Introduction

As early as 1891, Kummell et al. found that some middle-aged and elderly patients would gradually develop back pain and progressive kyphosis after minor trauma and go through an asymptomatic period of weeks to months. Due to the limitation of radiological examination technology, Kummell's description of the disease was limited to the observation of symptoms, without the support of imaging evidence. Meanwhile, the original intention of his report on this phenomenon was to distinguish it from the Pott's kyphosis in spinal tuberculosis.[1] With the emergence of radiological examination technology and progress, and the subsequent scholars confirmed that kummell's disease is essentially an old osteoporotic thoracolumbar fractures (OTF). Some patients will occur the ischemic osteonecrosis even nonunion of the vertebral body, that manifested with intravertebral cleft (IVC) or intravertebral vacuum phenomen.[2–7] Thus, the definition of this type of OTF is widely divergent. In honor of Kummell's contributions, early scholars used the name Kummell's disease, followed by a series of names reflecting different pathological changes of OTF, such as vertebral ischemic osteonecrosis or vertebral nonunion.[1,5,6] The above names only address the symptoms or pathological changes of patients with OTF, but cannot fully summarize the imaging characteristics. Due to the individual differences in the morphological characteristics of fractures and the symptoms of patients, the surgical algorithm is also controversial.[8–12] Thus, we proposed the new concept of chronic symptomatic osteoporotic thoracolumbar fractures (CSOTF). Based on the imaging characteristics of 368 patients with CSOTF, we designed a new classification system dividing these patients into 5 types, and evaluate the reliability. A treatment algorithm based on the classification was also proposed.

Materials And Methods

The Ethics Committee of Honghui Hospital approved this study. We retrospectively collected 6758 cases of OTF in our hospital from January 2010 to August 2017. The following diagnostic criteria for CSOTF were used: (1) supine position computed tomography (CT) scan or magnetic resonance imaging (MRI) exhibited signs of an IVC; (2) bone mineral density was less than or equal to -2.5 standard deviations (SD); and (3) exclusion of vertebral collapse caused by tumor or infection. A total of 483 (7.1%) patients were diagnosed with CSOTF after screening. We excluded cases involving multiple CSOTF or with incomplete imaging data to ensure the accuracy of the classification system. The imaging data of 368 patients of were ultimately used to develop the new classification system.

Radiological measurement

Due to the collapse of the vertebral endplate in patients of CSOTF, it is difficult to measure the local kyphosis angle accurately. It is usually that the injured vertebral kyphosis angle (VKA) refers to the angle between the extension lines of upper and lower end plates (Figure. 1A). However, it is really difficult to measure the VKA in the patients with severe wedging of vertebral body (vertebral collapse exceeds 50%) and hyperplastic osteophyte at the anterior margin of the vertebral body. Thus, we modified the measuring method of VKA to facilitate evaluating the stability of fractured vertebral body (Figure. 1B and C). The difference value (D-value) between the VKA measured on flexion and extension lateral radiography was used to evaluate the stability of the injured vertebra. In consideration that some patients aggravate their back pain during activity, the extent of flexion and extension are limited. A supine midsagittal CT scan can be a replacement for extension lateral radiography in some patients with severe back pain. A VKA D-value > 11° was identified as dynamic instability of the injured vertebra. CT and MRI was used to determine spinal stenosis caused by bone fragment compression of the spinal cord. The degree of local kyphosis was determined using the Cobb kyphosis angle (CKA). The angle formed by the line connecting the superior endplates of the upper adjacent vertebra and the inferior endplates of the lower adjacent vertebra was used to measure the CKA. A CKA > 30° on flexion and extension lateral radiography was identified as a kyphosis deformity.

Morphological classification

After analyzing and summarizing the imaging data of 368 cases, we revised the new classification system 3 times and finally reached a consensus. CSOTF were divided into 5 types based whether the CSOTF exhibited dynamic instability, spinal stenosis and/or kyphosis deformity (Table.1 and figure.2). Notably, the type I (dynamic stable type) is the basic type in our classification.

Table 1 *A new morphological classification system for* Chronic Symptomatic Osteoporotic Thoracolumbar Fracture

Type	Definition
Type I (dynamic stable type)	*It is characterized with the typical radiological changes, such as vertebral vacuum sign, intervertebral cleft, and/or pseudarthrosis.* The D-value of VKA is less than 11°.
Type II (dynamic unstable type)	The D-value of VKA is greater than 11°.
Type III (spinal stenosis type)	MRI reveals backward displacement of the bone fragments that leads to spinal canal stenosis and neurological deficit.
Type IV (kyphotic deformity type)	the CKA is greater than 30° on both flexion and extension lateral radiography.
Type V (mixed type)	Among the 3 aformentioned morphological changes from type II to IV, at least 2 types existed.

Reliability evaluation

We selected 10 spine surgeons who did not participate in the development of the classification system as evaluators and described the new classification system using illustrations in a PowerPoint presentation. All of the evaluators used the system to grade 10 cases of each type. The unqualified evaluators were re-examined after training to ensure that all evaluators were fully aware of the system. Forty additional cases were graded when 3 senior experts agreed that all investigators fully understood the system. A second round of grading was performed 1 month later, and the case order was scrambled using a random number generator. All cases included complete imaging data and symptom description.

The reliability of the classification system among different observers and the reproducibility for the same observer on separate occasions were assessed using the Kappa coefficient (κ). The coefficients were interpreted using the Landis and Koch grading system,[13] which defines κ values of less than 0.2 as slight agreement or reproducibility, between 0.2 and 0.4 as fair agreement or reproducibility, between 0.4 and 0.6 as moderate agreement or reproducibility, between 0.6 and 0.8 as substantial reliability or reproducibility, and greater than 0.8 as excellent reliability or reproducibility.

Results

Morphological classification

Among 368 patients of CSOTF, the population distribution for each type has been presented at Figure.3. The highest proportion for CSOTF was type I (56%), and the lowest proportion for CSOTF was type V (6%). The combinations constitute for type V include "type II + type III (n = 10, 2.7%) ", "type III + type IV (n = 6, 1.6%)", "type II + type IV (n = 4, 1.1%)" and "type II + type III + type IV (n = 2, 0.5%)".

Evaluation of Reliability

Ten evaluators performed a total of 800 assessments of 40 cases in 2 evaluation rounds. The most frequent CSOTF type was type III (23.9%), and the least frequently observed type was type V (15.4%) (Table 2).

Table 2
Frequency of Responses of Types

Type	Definition
Type I (dynamic stable type)	It is characterized with the typical radiological changes, such as vertebral vacuum sign, intervertebral cleft, and/or pseudarthrosis. The D-value of VKA is less than 11°.
Type II (dynamic unstable type)	The D-value of VKA is greater than 11°.
Type III (spinal stenosis type)	MRI reveals backward displacement of the bone fragments that leads to spinal canal stenosis and neurological deficit.
Type IV (kyphotic deformity type)	the CKA is greater than 30° on both flexion and extension lateral radiography.
Type V (mixed type)	Among the 3 aformentioned morphological changes from type II to IV, at least 2 types existed.

Interobserver reliability

The overall interobserver reliability was 0.83, which is considered excellent reliability (Table 3). The interobserver reliabilities for each CSOTF type were 0.82 for type I, 0.84 for type II, 0.91 for type III, 0.85 for type IV, and 0.71 for type V. These values indicate excellent reliability for types I, II, III and IV and substantial reliability for type V. The highest agreement was observed for type III (κ = 0.91). The lowest level of agreement was observed for type V (κ = 0.71).

Table 3
Interobserver Reliability

Type	No.	%
I	420	52.50
II	140	17.50
III	120	15.00
IV	80	10.00
V	40	5.00
Total	800	100

Intraobserver reliability

The average Kappa intraobserver reliability value for all types was 0.85, which is considered excellent reproducibility (Table 4). Six of the 10 evaluators exhibited excellent reproducibility results (κ > 0.80) for type of classification, and none of the evaluators exhibited moderate reproducibility results (κ < 0.60).

Table 4
Intraobserver Reliability

Type	Kappa
I	0.82
II	0.84
III	0.91
IV	0.85
V	0.71
Combined	0.83
Evaluator	**Kappa**
1	0.91
2	0.79
3	0.88
4	0.76
5	0.78
6	0.79
7	0.92
8	0.88
9	0.87
10	0.95
Average	0.85

Discussion

For the treatment of CSOTF, the following two classifications for Kümmell’s disease are currently recognized by most scholars.[9,14] Li et al[9] divided Kümmell's disease into 3 stages based on the degeneration of the adjacent intervertebral disc, the degree of vertebral height loss and its combination with spinal cord compression. However, the study by Li et al described the natural course of Kümmell's disease. This type of staging of Kümmell's disease is easy to understand and memorize, but it does not cover all of the fracture patterns found. Additionally, the type of Kümmell's disease was classified based on the height of the vertebral body and the degeneration of the adjacent intervertebral disc. However, the correlation between these two factors and the classification and treatment of Kümmell’s disease had not been proved in current literature. The recommended treatment is limited to percutaneous vertebroplasty or open internal fixation, and it is less practical in guiding treatment. In 2013, Patil et al[14] grouped Kümmell's disease patients based on the morphological patterns of fracture and proposed surgical options for each group. The morphological feature of kyphosis deformity was first used as a basis for classification. Kyphosis deformity greater than 30° on standing lateral radiography is classified as an independent type and treated using pedicle subtraction osteotomy (PSO) and posterior spinal instrumentation. However, in consideration of the possible dynamic instability of injured vertebral body in some cases, the kyphosis can be reduced or disappeared with changes in body position; and a large invasive treatment, such as PSO, may not necessary for these patients. Therefore, this classification system incompletely evaluates the kyphosis deformity. Additionally, in his classification system, axial instability of type I was not established due to the integrity of the posterior longitudinal ligament complex and the intervertebral joints. This classification system was also based only on 40 patients, which suggests that it is not comprehensive to cover all type injury.

This novel classification system is primarily based on 3 morphological features of dynamic instability of injured vertebra, spinal stenosis and kyphosis deformity. Many scholars have described dynamic instability as a unique phenomenon of Kümmell's disease,[1,8,10,11] but an accurate evaluation method for dynamic instability was lacking. Dynamic lateral radiography (flexion-extension radiograph) is a classic method for evaluating spinal stability, but it is not feasible for some patients with aggravated back pain during activity.[15] A supine midsagittal CT scan can be a replacement for extension lateral radiography in these patients. In consideration of the collapse of the vertebral endplate in patients of CSOTF, it is not feasible to draw a line on the collapsed end plate for the VKA measurement. Therefore, we modified the measuring method of VKA. Different from VKA that applied to evaluate the stability of fractured vertebral body, CKA reflect the degree of segment kyphosis between the upper and lower adjacent vertebraes, which was significant for assessing the necessity of correcting kyphosis. The degree of kyphosis in some patients with kyphosis deformity due to the dynamic instability of the injured vertebra may be reduced or disappear in the supine position. Different from the previous study[14], we defined kyphotic deformity type that the CKA is greater than 30° on dynamic lateral radiography not only the standing lateral radiography, which is valuable to screen out patients who really need correction operations.

Treatment algorithm

Different fracture patterns determine the patient's symptoms, which determines the corresponding surgical strategy. In this system, type I is the basic type of CSOTF, and more than half of the 368 patients exhibited this type (56%). The injured vertebra is relatively stable. Mild activity of the IVC may be the primary source of back pain. Therefore, we recommend vertebroplasty, which is performed via the injection of bone cement to eliminate the slight motion at the IVC, to relieve pain for this type (Fig. 4).

Type II is typical with dynamic instability of the injured vertebra. The apparent activity of the pseudarthrosis formed at the fracture region causes back pain. Previous studies have ignored the instability of the injured vertebrae, and patients with this type were treated using vertebroplasty. However, vertebroplasty alone is not suitable for this type. The fibrous tissue and hardened necrotic bone of the inner surface of the IVC obstruct the crosslinking of bone cement with the surrounding cancellous bone, which reduces the bond strength of the cement with the injured vertebra. Therefore, the instability of the vertebra will greatly increase the risk of bone cement displacement. Tsai et al[16] reported one case of Kümmell's disease in T12. Preoperative imaging revealed instability of the injured vertebrae, and bone cement displacement occurred 1 month after vertebroplasty. Therefore, vertebroplasty alone is not sufficient to stabilize the unstable segments. Additional posterior instrumentation and posterolateral fusion are safer surgeries (Fig. 5).

Type III is characterized by spinal stenosis. Patients experience symptoms of back pain usually accompanied by varying degrees of neurological deficits, especially intermittent claudication, which are caused by bone fragment compression of the spinal cord. The purpose of surgical treatment is to immediately relieve the compression and stabilize the injured segment. Therefore, decompression internal fixation and posterolateral fusion are recommended (Fig. 6). Li et al[9] and Zhang et al[10] reported that posterior decompression, short segmental pedicle screw fixation and posterolateral fusion combined with vertebroplasty achieved satisfactory results for the treatment of Kümmell's disease with neurological defict.

Type IV is characterized by kyphosis deformity. The local kyphosis is greater than 30°, even in the extension position. Muscle tension of the back triggered by the kyphosis deformity causes persistent back pain, disuse and atrophy of muscle. They may in turn affect the structure of the posterior tension bands that further aggravate kyphosis. For the patients only with the spasm of thoracolumbar muscles, the muscle relaxation under general anesthesia and nonunion of the vertebral body facilitate the correction of the kyphosis using the hyperextension position. Thus, a intraoperative examination should be performed firstly to verify whether the kyphosis can be corrected in an over-extending position under general anesthesia (Fig. 7). If the CKA is less than 30°after a hyperextension reduction under general anesthesia, a simple fixation and posterolateral fusion is adequate. Otherwise, different grades of osteotomy can be considered to achieve the correction based on the degree of kyphosis deformity.[17]

Type V is a mixed type that includes 2 or 3 morphological changes. This type includes "dynamic instability and spinal stenosis", "dynamic instability and kyphosis deformity", "spinal stenosis and kyphosis deformity" and "dynamic instability, spinal stenosis and kyphosis deformity". Among the morphological changes, it is usually that 1 or 2 pathology is the main reason to induce clinical symptom. The corresponding surgical strategies should take both the improvement of morphological changes and symptoms into consideration (Fig. 8).

Limitation

Our treatment recommendations are based on the characteristics of each type and our experience, which need to be verified by the further clinical study. Large-sample prospective clinical trials are required to confirm the effectiveness of the system to guide clinical treatment, especially balancing the benefit and complications when introducing the internal implant into the osteoporosis patients.

Conclusion

There are several modifications especially radiological measurement and treatment algorithm in our classification system. The results demonstrated that the interobserver reliability of the classification was 0.83, which indicates excellent agreement according to the Landis and Koch grading system. The highest agreement was observed for type III (κ = 0.91). One possible reason for this finding is that the morphological characteristic of type III, spinal stenosis, is the most easily identified. The interobserver reliability was lowest for type V, likely because type V is a mixed Kümmell's disease type. Different evaluators may have identified different morphological changes in the mixed type, which resulted in inconsistencies among evaluators. However, the κ coefficient for type V was 0.71, which indicates excellent agreement. The intraobserver reliability of the classification was 0.85, which is considered excellent reproducibility. Therefore, this study preliminarily demonstrated that the new classification system is simple, consistent convenient for communication and research.

Abbreviations

osteoporotic thoracolumbar fractures (OTF)

intravertebral cleft (IVC)

chronic symptomatic osteoporotic thoracolumbar fractures (CSOTF)

computed tomography (CT)

magnetic resonance imaging (MRI)

standard deviations (SD)

vertebral kyphosis angle (VKA)

difference value (D-value)

Cobb kyphosis angle (CKA).

Kappa coefficient (κ).

pedicle subtraction osteotomy (PSO)

Declarations

Ethics approval and consent to participate: The study was approved by the ethical committee of Honghui Hospital, Xi'an Jiaotong University. The patient gave written consent to for research applications of their clinical data. The patient data was anonymised in this study.

Consent for publication: Consent to publish was obtained from the patients detailed in this study.

Availability of data and materials: The datasets generated during the current study are public at the email dingjun.hao@qq.com.

Competing interests: The authors declare no conflict of interests.

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Authors' contributions: Conceived and designed the experiments: Hao DJ. Performed the experiments: Liu TJ and He BR. Collected the data: Tuo Y, Ge CY, Jia SJ, Liu P and Huang DG. Contributed reagents/materials/analysis tools: Zhang JN and Du JP. Wrote the paper: Yang JS and Tuo Y.

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Figures

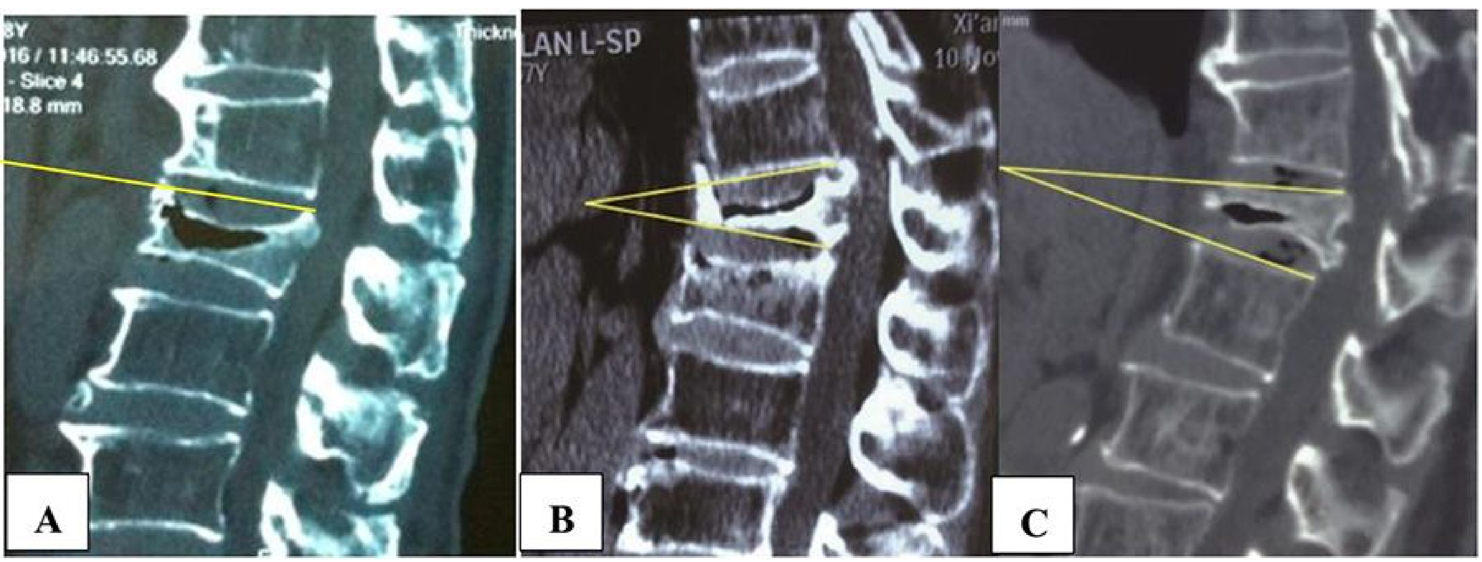

Figure 1

VKA assessment: the angle between the extension lines of upper and lower end plates (A); the angle formed by the line connecting the inferior endplates of the adjacent vertebra and the damaged vertebra when the superior endplate of the injured vertebra was collapsed (B); the line connecting the superior endplates of the adjacent vertebra and the damaged vertebra when the inferior endplate of the injured vertebra was collapsed (C).

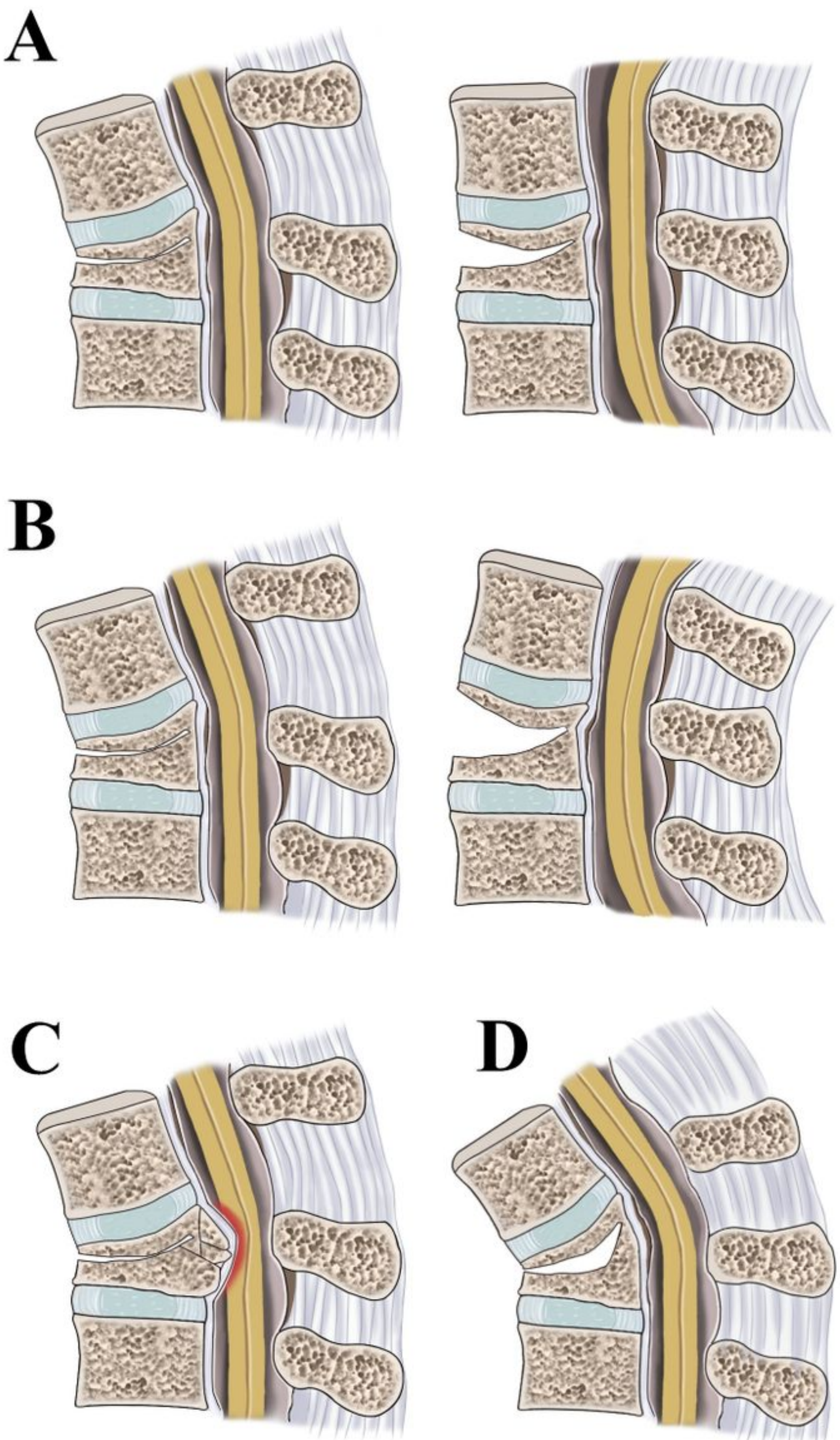

Figure 2

Panel A refers the Basic type (Type I); Panel B refers the Dynamic Instability type (Type II); Panel C refers the Spinal Stenosis type (Type III); Panel D refers the Kyphosis Deformity type (Type IV).

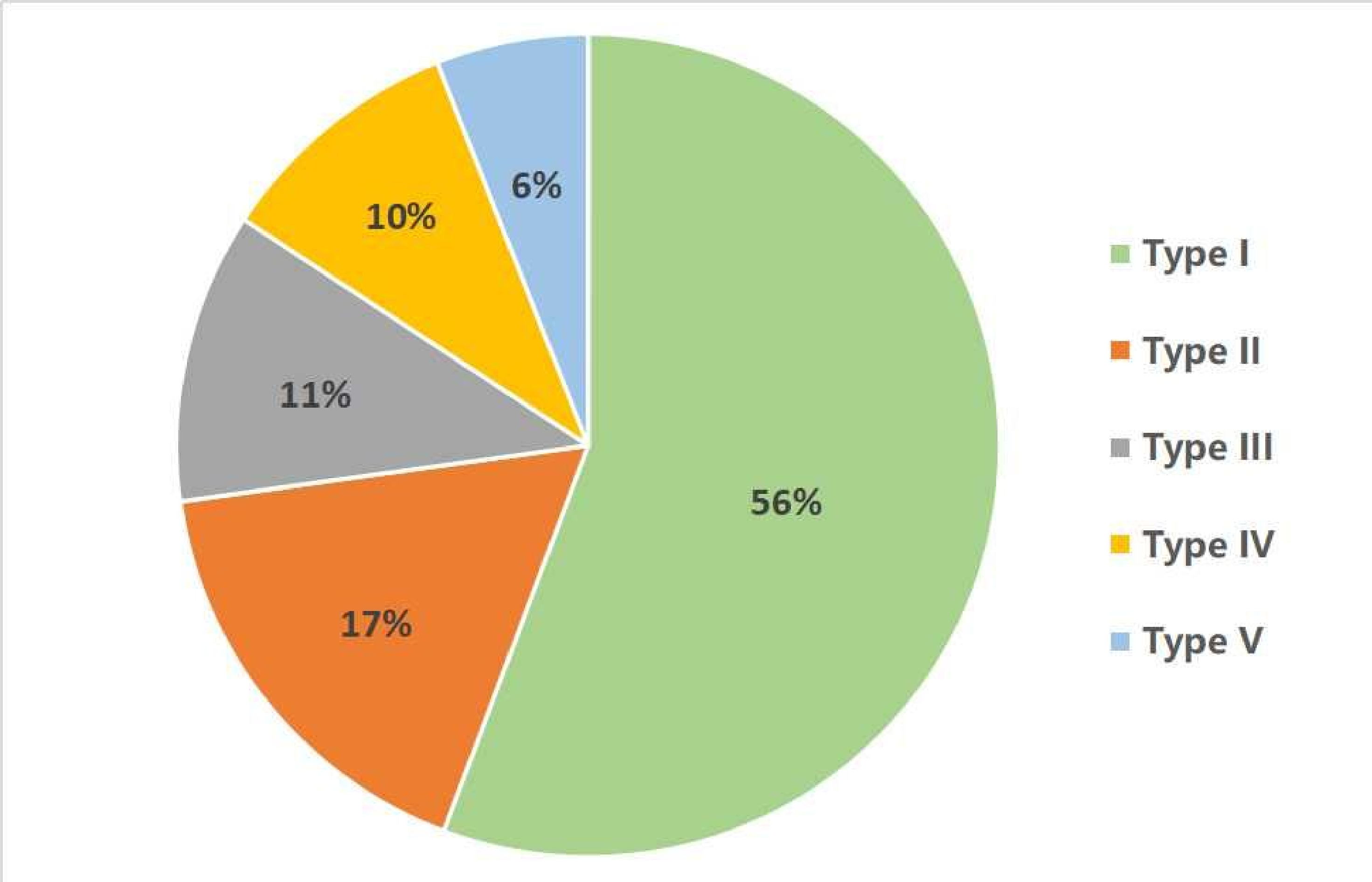

Figure 3

The population distribution for each type.

Figure 4

Type I treated with percutaneous vertebroplasty. Panel A, B and C showed the preoperative flexion lateral radiography, supine CT reconstruction view and MRI respectively. Panel D showed postoperative lateral radiography.

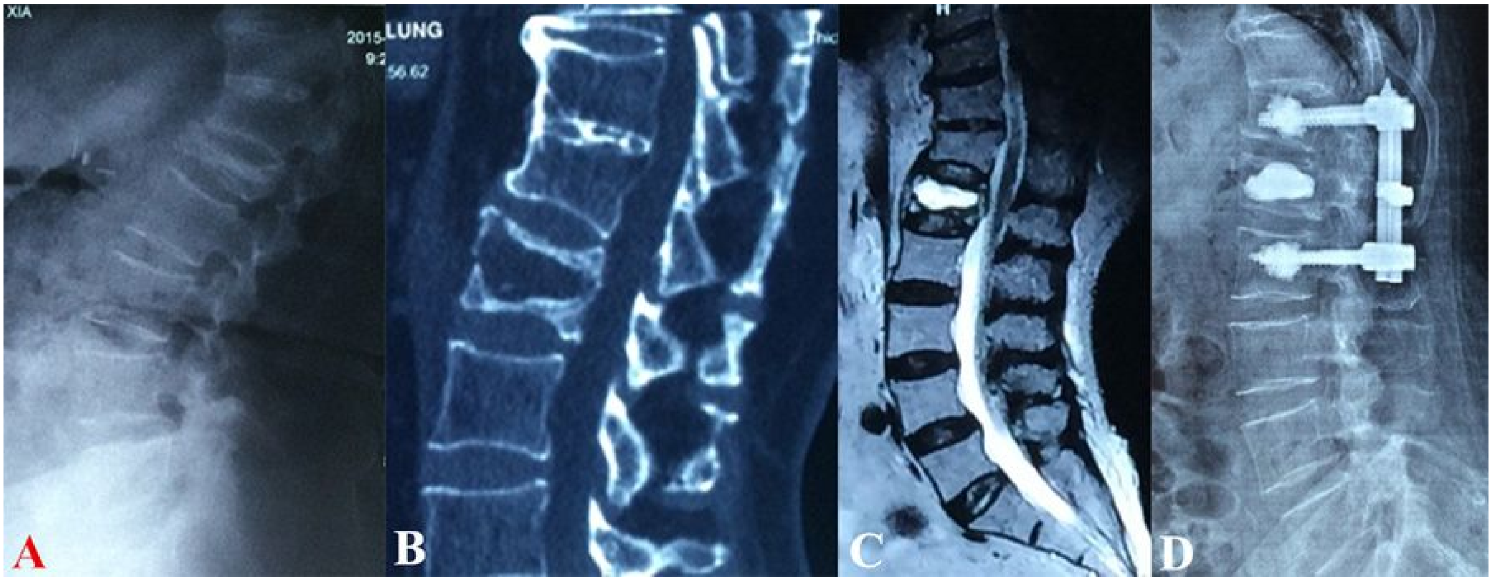

Figure 5

Type II treated using vertebroplasty with short-segment pedicle screw fixation and posterolateral fusion. Panel A, B and C showed the preoperative flexion lateral radiography, supine CT reconstruction view and MRI respectively. Panel D showed postoperative lateral radiography.

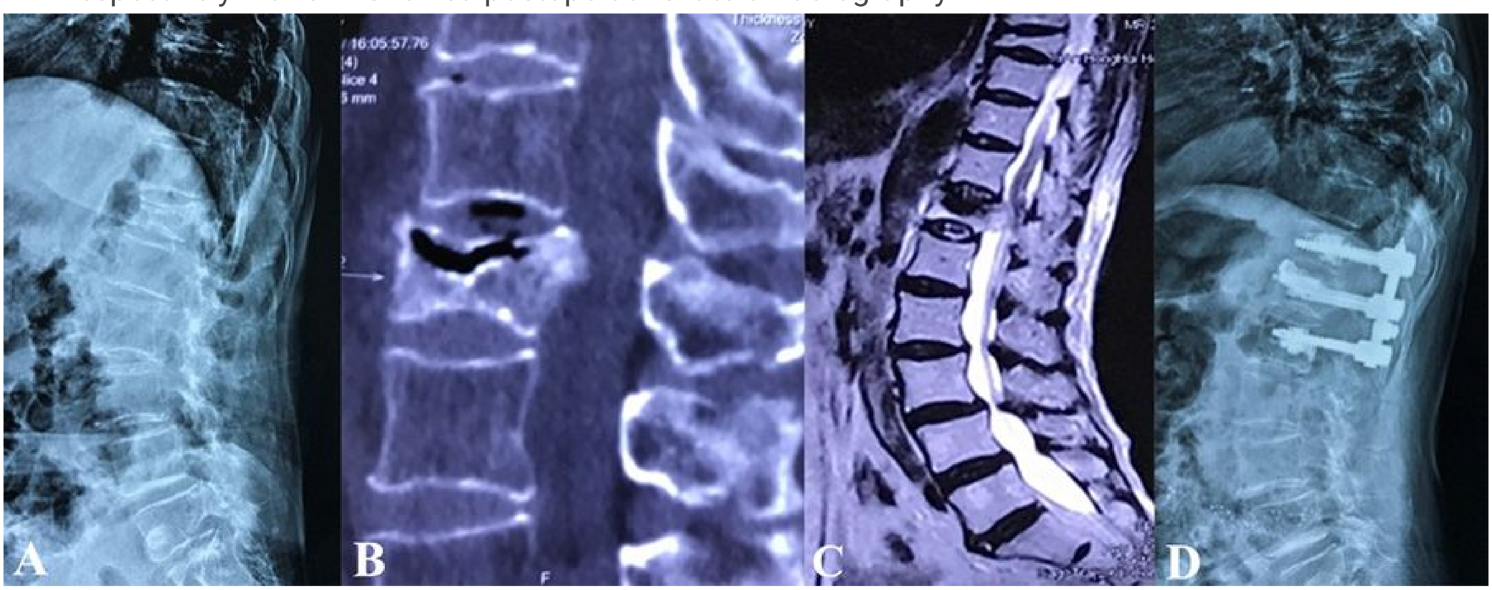

Figure 6

Type III was treated with posterior decompression and bone cement-augmented short-segment pedicle screw fixation and posterolateral fusion. Panel A, B and C showed the preoperative flexion lateral radiography, supine CT reconstruction view and MRI respectively. Panel D showed postoperative lateral radiography.

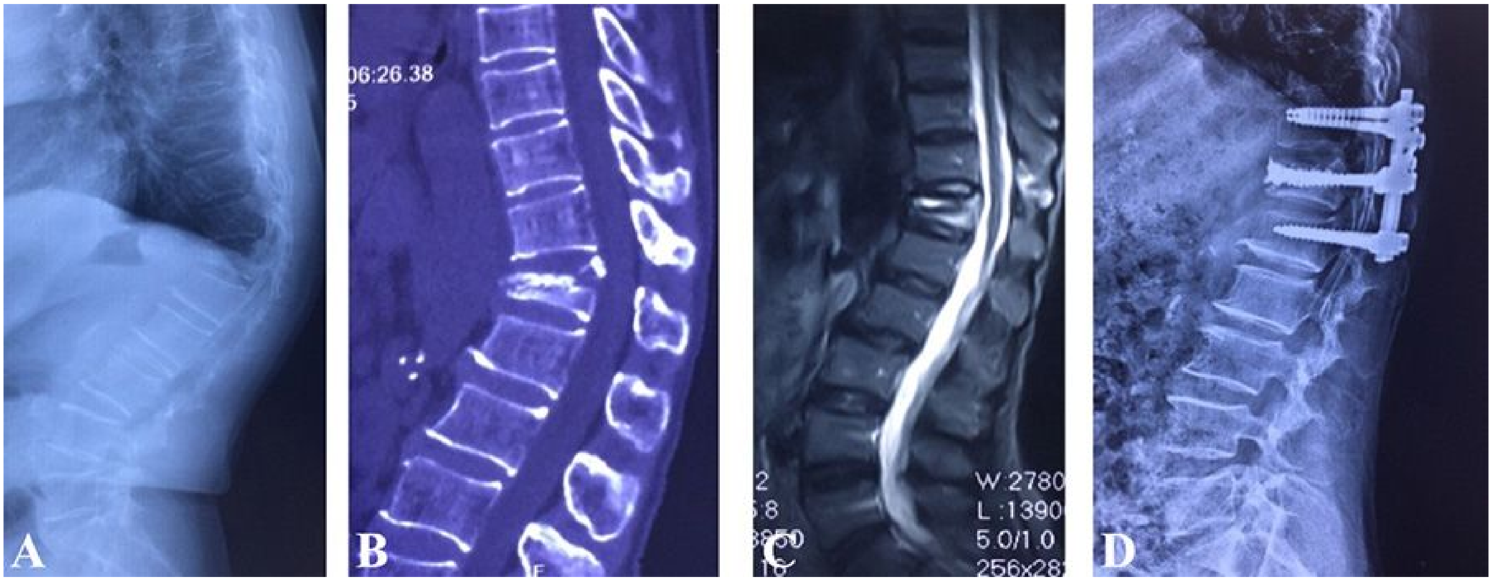

Figure 7

Type IV treated with over-extending position under general anesthesia combined with short-segment pedicle screw fixation and posterolateral fusion. Panel A, B and C showed the preoperative flexion lateral radiography, supine CT reconstruction view and MRI respectively. Panel D showed postoperative lateral radiography.

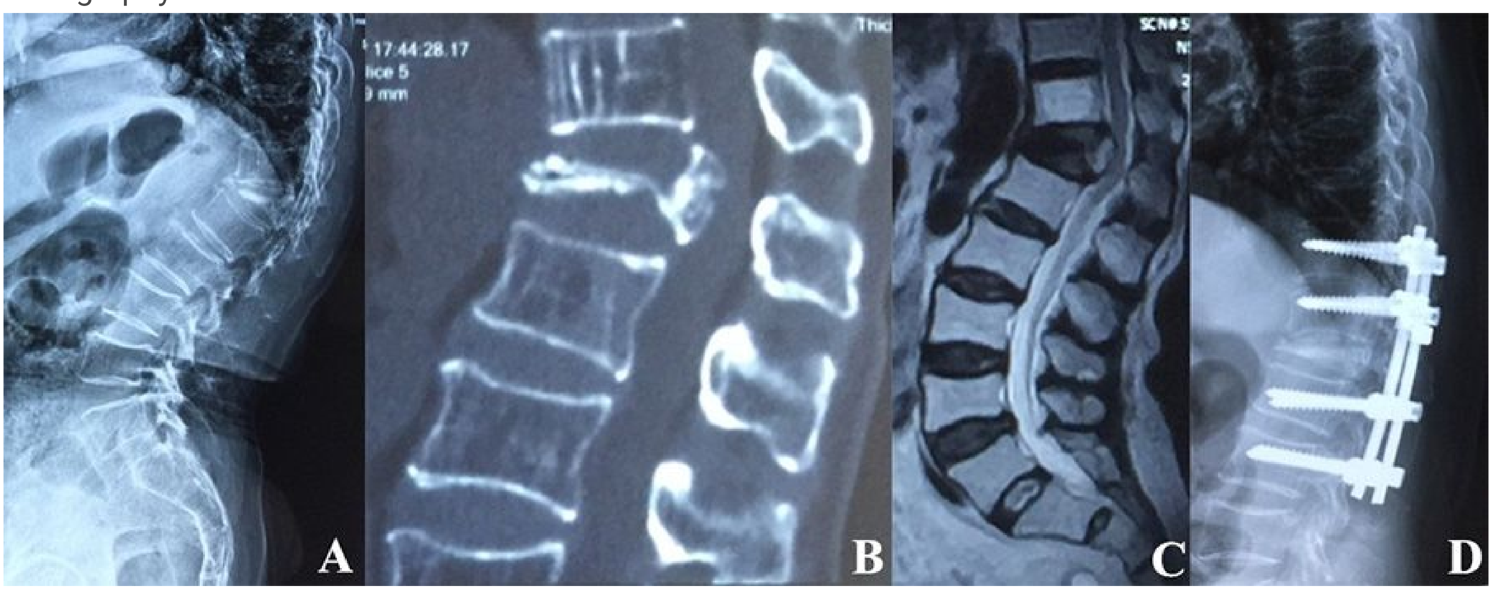

Figure 8

Type 8, the patient is characterized by " dynamic instabilityspinal stenosiskyphosis deformity ". The surgical approach is posterior decompression and pedicle screw fixation and fusion. Panel A, B and C showed the preoperative flexion lateral radiography, supine CT reconstruction view and MRI respectively. Panel D showed postoperative lateral radiography.