Application of finite element Analysis in dynamic changes of Spinal Mechanics in Osteoporotic Lumbar fracture

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Abstract

Aim: To explore the effect of finite element biomechanical properties of different methods in the treatment of osteoporotic thoracolumbar fractures.

Methods: Based on the ultra-thin CT scan data of a volunteer's thoracolumbar spine, the finite element method was used to simulate the treatment of osteoporotic thoracolumbar fracture. The images of thoracolumbar region were obtained by spiral CT scanning, and the three-dimensional geometric model was obtained by importing Mimics software, the finite element model of normal $T_{11} \sim L_2$ segment was established by finite element software Abaqus, and the validity of the model loading was verified. Based on the finite element model of T_{11} vertebral compression fracture based on normal raw data, the clinical overextension reduction manipulation was simulated by different treatment methods, and the changes of stress and displacement in different parts of injured vertebrae were analyzed.

Results: In this study, an effective finite element model of T_{11}-L_2 segment is established. The maximum stress, axial compression strength, axial compression stiffness (EF) and transverse shear stiffness (GF) of PKP and PVP treatment group were significantly better than those of conservative treatment group and open treatment group, and the difference was statistically significant. There was no significant difference between open treatment group and conservative treatment group, and there was no significant difference between PKP and PVP treatment group.

Conclusion: The results of finite element analysis show that PKP and PVP in the treatment of osteoporotic thoracolumbar fractures can effectively improve the condition of patients, relieve their clinical symptoms, have a good prognosis and have a good long-term effect, and its biomechanical properties are good, the application effect is remarkable.

Introduction

Osteoporosis is one of the common basic diseases in the elderly, calcium loss in the body, bone mass reduction, more prone to fracture, more likely to occur in the thoracolumbar vertebrae [1, 2]. Osteoporotic thoracolumbar fracture (OVF) is a common fracture type after osteoporosis in the elderly. The disease is characterized by osteopenia and degenerative changes of bone tissue structure. The main clinical manifestations are dyskinesia, low back pain, and loss of self-care ability and labor ability, which seriously affect the quality of life of the patients[3–6].In recent years, with the improvement of living standards and medical technology, the average life expectancy in China has been rising. With the arrival of the aging population, the incidence of osteoporotic thoracolumbar compression fractures in the elderly has increased year by year. It has still become a major killer of the health of the elderly[7, 8]. In addition, there is a lack of early diagnosis of osteoporotic lumbar fracture, and there is no unified standard to systematically evaluate the severity of osteoporotic lumbar fracture. Therefore, its serious morbidity and potential mortality are increasingly recognized as an important medical problem, seeking prevention, diagnosis and treatment of osteoporotic lumbar fracture is still a major clinical problem.

At present, the treatment of osteoporotic thoracolumbar fracture is mainly divided into conservative treatment and minimally invasive surgical treatment, conservative treatment includes bed rest, pain relief, anti-osteoporosis and brace fixation, but the treatment cycle is long and the effect is not ideal[9–11].With the development of minimally invasive technology, vertebroplasty has become the main method for the treatment of osteoporotic thoracolumbar fractures, and has achieved good results, but the patients' bone fractures heal slowly, and there is a risk of nerve injury, pulmonary embolism and other complications caused by leakage of filling materials[12–14]. However, this method is expensive and complex, so it has some limitations in clinical application. As the elderly patients with osteoporotic lumbar fracture have the characteristics of advanced age, many complications and high incidence of re-fracture, it is very important to evaluate the correct state of senile osteoporotic thoracolumbar fracture and choose reasonable treatment methods.Based on this, this study intends to use conservative treatment, percutaneous vertebroplasty (PVP), percutaneous kyphoplasty (PKP) and open surgery to treat patients with thoracolumbar fractures through finite element analysis from the point of view of biomechanical properties. The biomechanical properties of biomechanical axial compression strength (σ c) and axial compression stiffness (EF) of each group were compared, to make the best treatment plan qualitatively and quantitatively for the selection of clinical prevention and treatment methods.

Materials And Methods

Modeling research object

A volunteer (body mass 70kg, height 172cm) was selected and CT scan was used as the basis for building a perfect model.The CT scanning data of thoracolumbar vertebrae of volunteers were obtained, and the patients were placed in supine position, then spiral CT was used to scan the spine of T_{11} ~ L_2 continuously with 0.62mm spacing, and the CT images of T_{11} ~ L_2 segments in Dicom format were obtained. Scanning conditions: 120kV 125mA, layer thickness 0.62 mm, layer spacing 0.62mm.The finite element method was used to compare the efficacy of four treatments in the treatment of osteoporotic thoracolumbar fractures. The three-dimensional finite element model of thoracolumbar fracture was established by Mimics, SolidWorks, Abaqus and other software, and four different treatment methods were implanted respectively, One is to simulate the conservative treatment, the second is to simulate the open surgical treatment, the third is to simulate the percutaneous kyphoplasty, and the fourth is to simulate the percutaneous vertebroplasty.

Instrumentation and analysis software

Mimics17.0Software (Materialise,Belgium); Geomagic Studio11 (Geomagic, USA); SolidWorks 2015 (Dassault systems S.A, USA); ABAQUS 2016 (Dassault systems S.A, USA);Multi-layer spiral CT (GE, USA).

Inclusion criteria

The patients with thoracolumbar fracture were diagnosed by MRI, CT and X-ray examination;The dual energy X-ray absorptiometry showed that the bone mineral density T value was less than-2.5 and there was osteoporosis;Low back pain, aggravated when lying in bed and turning over and getting up, sitting and standing, and relieved in supine position;The clinical data were complete;The vertebrae, ligaments and facet joints were intact;No congenital malformation or tumor in the patient;Patients or their families sign informed consent and voluntarily participate in treatment.

Exclusion criteria

Exclusion of compression fractures caused by multiple myeloma;Complicated with pedicle fracture and spinal cord injury;Complicated with severe heart, brain, liver, kidney, endocrine, malignant tumor and other diseases;Abnormal blood coagulation or congenital blood system disease;Patients with incomplete collection of medical records.

Treatment method

** Conservative treatment**

The patients were treated conservatively, let the patients rest on the hard bed, give the corresponding painkillers according to the degree of pain, stop the painkillers when the pain is tolerable or disappear completely, give the anti-osteoporosis vitamin D_3 treatment, and let the patients wear waist brace for functional exercise 2 months later.

** Open surgical treatment**

After anesthesia, the patient was placed in the prone position, and after disinfection, the injured vertebra was taken as the central longitudinal incision to expose the pedicle pedicle of the injured vertebra and the upper and lower adjacent vertebrae. The pedicle screw was screwed in advance and then exited. The bone cement of the preparation number was injected into the PVP tube. After the bone cement was well dispersed, it was screwed into the pedicle screw and solidified. After total laminectomy and decompression, the connecting rod of the spinal internal fixation device was installed and then the reduction was extended. The stitches were removed 14 days after operation, and the patients wore lumbar brace to get out of bed 2 weeks later.

** percutaneous kyphoplasty(PKP)**

After disinfection, the skin was cut open, punctured through the pedicle approach to 5cm of the posterior wall of the vertebral body, entered the guide needle, along the guide needle into the dilation tube channel, into the balloon dilator, and then injected polymethyl methacrylate (PMMA), to be solidified by PMMA. After the operation, the patient needs to go to the pillow and lie flat for 6 hours, and then the patient wears a waist brace to get out of bed.

** percutaneous vertebroplasty(PVP)**

The patient was in prone position and gently manipulated under the guidance of C-arm machine after local anesthesia to make the shape of bilateral vertebral arch symmetrical. After disinfection, the needle was punctured to the third place of the vertebral body, and the bone cement was slowly injected into the injured vertebra with a pressure syringe. The distribution of bone cement was observed at any time by C-arm machine. After the operation, 30min was transferred to the ward, and the patient needed to go to the pillow and lie flat for 6 hours, and then the patient wore a waist brace to get out of bed.

Observation index

Statistics of the maximum stress value of the four groups of models; the stress changes of the facet joints in different intervertebral spaces under different movements after the static load of the model; the axial compression strength of four treatment methods of thoracolumbar fracture; the stiffness of four treatment methods of thoracolumbar fracture.

Statistical analysis

Use SPSS 23. 0 statistical software was used for analysis, and t-test was used to compare the biomechanics of T_{11} ~ L_2 segments in normal state and fracture state. With normal biomechanics as the control group, the biomechanics of each group was analyzed by single factor analysis of variance (One-way ANOVA) and multiple comparison LSDtest ($P < 0.05$) after different treatments. 05 means that the difference is statistically significant.

Results

T_{11}-L_2 segment finite element model

The model includes cortical bone, cancellous bone, posterior longitudinal ligament, anterior longitudinal ligament, facet joint, fibrous annulus, nucleus pulposus, ligament flavum, interspinous ligament, articular capsule ligament, supraspinous ligament and so on. The model has 209,026 elements and 61,738 nodes, as shown in Fig.1.

Verification of the validity of the model

The range of motion (ROM) of T_{11} ~ L_2 segment is as follows: T_{11} ~ L_1 flexion (2.42 °), L_1 ~ L_2 flexion (2.39 °), T_{11} ~ L_1 dorsal extension (2.31 °), L_1 ~ L_2 dorsal extension (2.48 °), T_{11} ~ L_1 lateral bending (2.55 °), L_1 ~ L_2 lateral bending (2.60 °), T_{11} ~ L_1 axial rotation (1.38 °), L_1 ~ L_2 axial rotation (1.39 °). The range of motion of the model is similar to that of the literature[15], as shown in Fig.2.

It can be seen from Tab.1 that under the trend of gradual increase of stress, the comprehensive stress changes of the seven working conditions in the conservative treatment group are the largest, indicating that if the stress concentration of the thoracolumbar vertebrae increases significantly after the treatment of thoracolumbar fractures with this method, the risk of re-fracture after continued compression is still high. After open surgery, the comprehensive stress change of 7 working conditions was smaller than that of conservative treatment group, indicating that if the stress concentration of thoracolumbar vertebrae increased significantly, the risk of re-fracture decreased after continued compression. After PKP and PVP treatment, the comprehensive stress changes of the seven working conditions of the model are small, indicating that after this method for the treatment of thoracolumbar fracture, if the stress concentration of thoracolumbar vertebrae increases significantly, the risk of re-fracture is smaller.

Tab.1 Comparison of maximum stress values of four groups of models (, mPA)

Working condition	Conservative treatment group	Open surgical treatment group	PKP group	PVP group
Vertical load	11.97±4.29	11.61±3.26	10.87±1.98	10.67±5.17
Anteflexion	42.24±7.92	41.87±9.03	35.10±6.09	37.27±2.92
Extension	42.72±6.28	41.64±7.35	39.79±8.03	38.07±5.58
Left flexion	54.49±8.01	42.72±3.65	36.24±3.97	37.31±4.12
Right flexion	52.63±6.77	41.70±7.02	35.03±2.55	38.20±2.84
Left rotation	16.17±5.11	13.22±1.60	13.24±2.04	13.18±2.13
Right rotation	14.42±2.15	11.74±1.04	11.55±0.99	11.72±1.79

Axial Compression strength of four treatment methods for Thoracolumbar fracture

The so-called strength of thoracolumbar vertebrae refers to the ability of thoracolumbar vertebrae to resist destruction under load, indicating the strength of thoracolumbar vertebrae after different treatments. Conservative treatment, open treatment, PKP treatment and PVP were used to treat osteoporotic thoracolumbar fractures, there was no significant difference between PKP group and PVP group, but the axial compression strength of PKP and PVP treatment group was significantly higher than that of conservative treatment group, and the difference was statistically significant (t=3.043, *P*=0.067). The results are shown in Fig.4. The results are as follows: the axial compression strength of PKP and PVP treatment group is significantly higher than that of conservative treatment group (t=4.721, *P*=0.048); the experimental results show that the therapeutic effect of PKP and PVP is better, but there is a significant difference between them.

Stiffness of four treatment methods for thoracolumbar fracture

The axial stiffness of thoracolumbar vertebrae indicates the ability of resisting axial deformation of thoracolumbar vertebrae under load, which is one of the mechanical indexes of stability of thoracolumbar internal fixation. Osteoporotic thoracolumbar fractures were treated with open treatment, PKP treatment and PVP, the axial compression stiffness (EF) of the four groups showed PKP treatment and > PVP treatment > open treatment > conservative treatment, and there was no significant difference in the axial compression strength between PKP group and PVP group (t=3.482, *P*=0.057; t=3.121, *P*=0.061), but the axial compression strength of PKP and PVP treatment group was significantly higher than that of conservative treatment group, the difference was statistically significant (t=4.223, *P*=0.046). The transverse shear stiffness (GF) of open treatment group, PKP treatment group and PVP treatment group was similar to that of conservative treatment group, and that of PKP treatment group was similar to that of PVP treatment group, but there was no significant difference ($t=3.081$, $P=0.052$; $t=3.742$, $P=0.057$). The axial compression strength of PKP and PVP treatment group was significantly higher than that of conservative treatment group, and the difference was statistically significant ($t=4.043$, $P=0.044$). The experimental results showed that the effect of PKP and PVP treatment was better, but there was a significant difference between the two groups.

Discussion

Osteoporosis is a systemic skeletal disease, its occurrence and development is the result of the comprehensive action of many systems, such as nerve, endocrine, immunity, reproduction, musculoskeletal and so on, it is characterized by decreased bone mass, bone microstructure degeneration, increased bone brittleness, pain, lumbar and knee soreness, spinal deformation and other symptoms, resulting in bone brittleness and fracture susceptibility, in clinical treatment, it is found that osteoporosis is one of the main causes of fracture in the elderly[16].According to the results of an epidemiological survey conducted by the China National Health Commission, about 19.2% of people over the age of 50 suffer from osteoporosis, with an incidence of 32.0% among people over 65, and the incidence in postmenopausal women is much higher than that in men[17].Osteoporotic thoracolumbar fracture is one of the common complications of osteoporosis, and which is an aging disease characterized by low back pain and limited movement, it is estimated that the prevalence rate of vertebral fractures in different parts of the world is about 16–21%, of which 30–50% of patients will have back pain, kyphosis and acute vertebral dyskinesia, neurological dysfunction caused by spinal cord injury[18].The risk factors of osteoporotic vertebral fracture mainly include rheumatoid arthritis, type 2 diabetes mellitus (T2DM), the use of glucocorticoid and immunosuppressant, low body mass index and so on, and the strongest risk factors for osteoporotic vertebral fracture are advanced age and bone mineral density (BMD)[19–21] .Although osteoporotic vertebral fractures usually occur in the thoracolumbar transitional zone, osteoporotic lumbar fractures are also common in the elderly in recent years, most often at the L4/L5 level, the prevalence of lumbar fractures in osteoporotic vertebral fractures is about 4–8%, osteoporotic lumbar fractures are also a common indication for spinal surgery worldwide[22].At present, osteoporotic fracture is considered to be an important public health problem, which not only increases the morbidity and mortality of elderly patients, but also produces very important economic costs. In addition, osteoporotic lumbar fracture often causes spinal cord injury, which is the main cause of disability, quality of life and even death in the elderly, seriously affecting the quality of life of patients and their families[1].However, there is a lack of early diagnosis of osteoporotic lumbar fracture, and there is no unified standard to systematically evaluate the severity of osteoporotic lumbar fracture, therefore, its serious morbidity and potential mortality are increasingly recognized as an important medical problem, and seeking prevention, diagnosis and treatment of osteoporotic lumbar fracture is still a major clinical problem.

Thoracolumbar vertebrae refers to T_{11}-L_2, a special segment of the spine, because it is located between the fixed thoracic vertebrae and the active lumbar vertebrae, the anatomical structure is relatively special, and it is the stage of transition from the physiological kyphosis of the thoracic vertebrae to the physiological protrusion of the lumbar vertebrae, so it is easy to cause injury in stress, so it is easy to cause injury[23].With the increase of age, the thoracolumbar vertebrae tend to show progressive degenerative changes, which causes them to become more fibrotic and not uniformly distribute compressive stress, thus exposing some parts of the vertebral body to high stress concentration, the trabecular bone adjacent to the endplate can then adapt to the changed force distribution according to Wolf's law, giving the observed changes in bone architecture and density. Osteoporosis affects the spine in another way, and severe osteoporosis affects the shape of the bone, resulting in a change in the height of the lumbar vertebrae, causing the arch of the adjacent vertebrae to move closer[24].According to the spinal three-column theory[25], the lumbar vertebrae mainly play the role of buffering and dispersing stress in spinal mechanics, when osteoporosis occurs in the lumbar vertebrae, the way in which the vertebrae bear the transmission force will also be changed. Osteoporotic vertebral compression fracture reduces the strength of the vertebral body and loses the stability of the spine, at the same time, due to the fretting of the fracture site, it may stimulate the peripheral nerves of bone marrow and periosteum and produce a sense of pain. Therefore, it is very important to study the biomechanics of this section. From the biomechanical point of view, the purpose of the treatment of thoracolumbar fractures is to restore the strength, stiffness and stability of the thoracolumbar spine and achieve the bony healing of the thoracolumbar vertebrae, and the biomechanical experimental results show that PKP and PVP can meet this requirement for osteoporotic thoracolumbar fractures. The experimental results show that the biomechanical properties of the model are significantly improved after PKP and PVP treatment, which can not only meet the requirements of normal functional kinematics of thoracolumbar vertebrae, but also restore the stability of thoracolumbar vertebrae.

At present, there are many research methods about biomechanics, among which finite element analysis, as a new biomechanical research method, has highlighted its unique superiority since its application, however, this method is not very mature at present, and there are still many defects, such as time-consuming, data loss, not all lifelike appearance and so on[26]. With the unremitting efforts of many scholars in the past years, the clinical value of the finite element model of thoracolumbar spine is increasing, its shape is becoming more and more realistic, and its biological characteristics are getting closer and closer to the real law of motion of the human body.Under the environment of the above-mentioned advantages, this study takes the bone structure data of a patient with osteoporotic thoracolumbar fracture as the research object, uses the ultra-thin CT scanning technology to obtain the sectional image of T_{11}-L_2, and the authenticity of the original data needed for modeling is high, the CT thin layer scanning image is read into the Mimics software to establish the geometric model, and the Mimics software can automatically assign materials according to the CT value of the original data of the model, and it makes the assignment accurate and fast, so as to ensure the high accuracy of the model seen in this study.

For fracture reduction surgery, percutaneous kyphoplasty has been widely used in the treatment of thoracolumbar fractures, this method can not only restore vertebral body height and correct vertebral kyphosis deformity, but also relieve pain,it can also reduce the leakage rate of bone cement and complications such as nerve injury and pulmonary embolism[27]. It has been reported that PKP in the treatment of thoracolumbar fracture has the characteristics of short operation time, less trauma, low cost, short radiotherapy time and so on, it has clinical application value[28].In the results of this study, there was no significant difference in the peak stress and displacement of the model after PKP and PVP treatment, but the difference was basically similar, and the peak difference was small.

In this study, the commonly used static fixation simulation method is used to simulate the biomechanics of different treatment methods of osteoporotic thoracolumbar fracture, in real life, the thoracolumbar spine is mainly subjected to the dynamic force in the process of action life, at the same time, muscles and other soft tissues will also have a certain impact on the force of the thoracolumbar vertebrae. Therefore, this study only reflects the stress of the thoracolumbar vertebrae under a certain action, and the later stage needs to be combined with the dynamic analysis of the musculoskeletal system to provide more accurate and practical simulation results for the clinic.

To sum up, the results of finite element analysis show that PVP and PKP in the treatment of osteoporotic thoracolumbar fracture can effectively improve the condition of patients, alleviate their clinical symptoms, have a good prognosis, have a good long-term effect, and have good biomechanical properties and remarkable application effect.

Declarations

Ethics approval and consent to participate：

Consent for publication:Written informed consent was obtained from the patient for publication of this case report and any accompanying images.

Competing Interests：The authors declared no potential conflicts of interest with respect to the research, author- ship, and/or publication of this article.

Author contributions：Yan Jianwen carried out the experimental work and the data collection and interpretation. Yu Yafang participated in the design and coordination of experimental work, and acquisition of data.Liao Zhong participated in the study design, data collection, analysis of data and preparation of the manuscript. Yan Jianwen carried out the study design, the analysis and interpretation of data and drafted the manuscript. All authors read and approved the final manuscript.

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References

1. E. Lopez, E. Ibarz, A. Herrera, S. Puertolas, S. Gabarre, Y. Mas, J. Mateo, J. Gil-Albarova and L. Gracia, A predictive mechanical model for evaluating vertebral fracture probability in lumbar spine under different osteoporotic drug therapies, Computer methods and programs in biomedicine, **131** (2016), 37–50.
2. M. Szamatowicz, How can gynaecologists cope with the silent killer - osteoporosis?, Przeglad menopauzalny = Menopause review, **15** (2016), 189–192.
3. Y. Zong, Y. Tang, Y. Xue, H. Ding, Z. Li, D. He, Y. Zhao and P. Wang, Depression is associated with increased incidence of osteoporotic thoracolumbar fracture in postmenopausal women: a prospective study, European spine journal: official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society, **25** (2016), 3418–3423.
4. N.C. Wright, A.C. Looker, K.G. Saag, J.R. Curtis, E.S. Delzell, S. Randall and B. Dawson-Hughes, The recent prevalence of osteoporosis and low bone mass in the United States based on bone mineral density at the femoral neck or lumbar spine, Journal of bone and mineral research: the official journal of the American Society for Bone and Mineral Research, **29** (2014), 2520–2526.
5. Z. Xu, D. Hao, L. He, H. Guo, B. He, T. Liu, Y. Zheng and D. Wang, An assessment system for evaluating the severity of thoracolumbar osteoporotic fracture and its clinical application: A retrospective study of 381 cases, Clinical neurology and neurosurgery, **139** (2015), 70–75.
6. S.M. Lee, H.S. Oh, S.H. Lee, H.C. Lee and B.W. Hwang, Cement Augmented Anterior Reconstruction and Decompression without Posterior Instrumentation: A Less Invasive Surgical Option for Osteoporotic Thoracolumbar Fracture with Cord Compression, Korean journal of neurotrauma, **16** (2020), 190–199.
7. J. Chapman, J.S. Smith, B. Kopjar, A.R. Vaccaro, P. Arnold, C.I. Shaffrey and M.G. Fehlings, The AOSpine North America Geriatric Odontoid Fracture Mortality Study: a retrospective review of mortality outcomes for operative versus nonoperative treatment of 322 patients with long-term follow-up, Spine, **38** (2013), 1098–1104.
8. T.W. O'Neill, W. Cockerill, C. Matthis, H.H. Raspe, M. Lunt, C. Cooper, D. Banzer, J.B. Cannata, M. Naves, B. Felsch, D. Felsenberg, J. Janott, O. Johnell, J.A. Kanis, G. Kragl, A. Lopes Vaz, G. Lyritis, P. Masaryk, G. Poor, D.M. Reid, W. Reisinger, C. Scheidt-Nave, J.J. Stepan, C.J. Todd, A.D. Woolf, J. Reeve and A.J. Silman, Back pain, disability, and radiographic vertebral fracture in European women: a prospective study, *Osteoporosis international: a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA*, **15** (2004), 760–765.

9. D. Yu, S. Kim and I. Jeon, Therapeutic Effect of Teriparatide for Osteoporotic Thoracolumbar Burst Fracture in Elderly Female Patients, Journal of Korean Neurosurgical Society, **63** (2020), 794–805.
10. J.A. Hirsch, R.V. Chandra, V. Pampati, J.D. Barr, A.L. Brook and L. Manchikanti, Analysis of vertebral augmentation practice patterns: a 2016 update, Journal of neurointerventional surgery, **8** (2016), 1299–1304.
11. W. Clark, P. Bird, P. Gonski, T.H. Diamond, P. Smerdely, H.P. McNeil, G. Schlaphoff, C. Bryant, E. Barnes and V. Gebski, Safety and efficacy of vertebroplasty for acute painful osteoporotic fractures (VAPOUR): a multicentre, randomised, double-blind, placebo-controlled trial, Lancet, **388** (2016), 1408–1416.
12. J.S. Park, J. Kim, Y. Lee, J.G. Gwon and Y.S. Park, Intra-cardiac Embolism of a Large Bone Cement Material after Percutaneous Vertebroplasty Removed through a Combination of an Endovascular Procedure and an Inferior Vena Cava Exploration: a Case Report, Journal of Korean medical science, **33** (2018), e141.
13. X.G. Deng, X.M. Xiong, D. Wan, H.G. Shi, G.L. Mei and W. Cui, Modified percutaneous Kyphoplasty technique in the treatment of osteoporotic thoracolumbar burst fractures: could it reduce the odds of cement leakage?, BMC surgery, **20** (2020), 96.
14. Z. Li, Y. Wang, Y. Xu, W. Xu, X. Zhu and C. Chen, Efficacy analysis of percutaneous pedicle screw fixation combined with percutaneous vertebroplasty in the treatment of osteoporotic vertebral compression fractures with kyphosis, Journal of orthopaedic surgery and research, **15** (2020), 53.
15. M. Couvertier, A. Germaneau, M. Saget, J.C. Dupre, P. Doumalin, F. Bremand, F. Hesser, C. Breque, M. Roulaud, O. Monlezun, T. Vendeuvre and P. Rigoard, Biomechanical analysis of the thoracolumbar spine under physiological loadings: Experimental motion data corridors for validation of finite element models, *Proceedings of the Institution of Mechanical Engineers. Part H, Journal of engineering in medicine*, **231** (2017), 975–981.
16. C.M. Weaver, C.M. Gordon, K.F. Janz, H.J. Kalkwarf, J.M. Lappe, R. Lewis, M. O'Karma, T.C. Wallace and B.S. Zemel, The National Osteoporosis Foundation's position statement on peak bone mass development and lifestyle factors: a systematic review and implementation recommendations, Osteoporosis international: a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA, **27** (2016), 1281–1386.
17. J.A. Kanis, Diagnosis of osteoporosis and assessment of fracture risk, Lancet, **359** (2002), 1929–1936.
18. P. Wang, F. Wang, Y.L. Gao, J.Q. Li, J.T. Zhang, D.C. Miao and Y. Shen, Lumbar spondylolisthesis is a risk factor for osteoporotic vertebral fractures: a case-control study, The Journal of international medical research, **46** (2018), 3605–3612.
19. O. Ishida, T. Furuya, E. Inoue, K. Ochi, K. Ikari, A. Taniguchi, H. Yamanaka and S. Momohara, Risk factors for established vertebral fractures in Japanese patients with rheumatoid arthritis: Results from a large prospective observational cohort study, Modern rheumatology, **25** (2015), 373–378.

20. C.H. Tseng, Metformin use is associated with a lower risk of osteoporosis/vertebral fracture in Taiwanese patients with type 2 diabetes mellitus, European journal of endocrinology, **184** (2021), 299–310.
21. W.J. Hong, W. Chen, K.J. Yeo, P.H. Huang, D.Y. Chen and J.L. Lan, Increased risk of osteoporotic vertebral fracture in rheumatoid arthritis patients with new-onset cardiovascular diseases: a retrospective nationwide cohort study in Taiwan, *Osteoporosis international: a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA*, **30** (2019), 1617–1625.
22. M. Kohno, Y. Iwamura, R. Inasaka, K. Kaneko, M. Tomioka, T. Kawai, Y. Aota, T. Saito and Y. Inaba, Surgical Intervention for Osteoporotic Vertebral Burst Fractures in Middle-low Lumbar Spine with Special Reference to Postoperative Complications Affecting Surgical Outcomes, *Neurologia medico-chirurgica*, **59** (2019), 98–105.
23. Q. Li, C. Yun and S. Li, Transpedicular bone grafting and pedicle screw fixation in injured vertebrae using a paraspinal approach for thoracolumbar fractures: a retrospective study, Journal of orthopaedic surgery and research, **11** (2016), 115.
24. P. Pollintine, P. Dolan, J.H. Tobias and M.A. Adams, Intervertebral disc degeneration can lead to "stress-shielding" of the anterior vertebral body: a cause of osteoporotic vertebral fracture?, Spine, **29** (2004), 774–782.
25. F. Denis, The three column spine and its significance in the classification of acute thoracolumbar spinal injuries, Spine, **8** (1983), 817–831.
26. U. K and V. R, Finite element analysis of lower limb exoskeleton during sit-to-stand transition, Computer methods in biomechanics and biomedical engineering (2021), 1–7.
27. J.Z. Chang, M.J. Bei, D.P. Shu, C.J. Sun, J.B. Chen and Y.P. Xiao, Comparison of the clinical outcomes of percutaneous vertebroplasty vs. kyphoplasty for the treatment of osteoporotic Kummell's disease:a prospective cohort study, BMC musculoskeletal disorders, **21** (2020), 238.
28. R. Wan and S. Liu, Efficacy and safety of unilateral and bilateral percutaneous balloon kyphoplasty for AOspineA3/A4 osteoporotic thoracolumbar burst fractures, Medicine, **99** (2020), e21276.

Figures

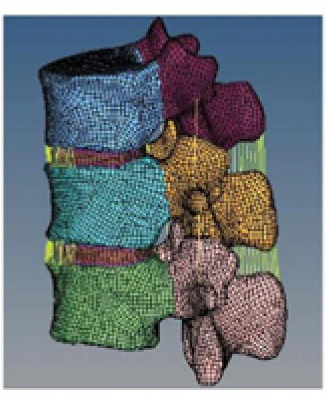

Figure 1

T_{11}-L_2 segment finite element model

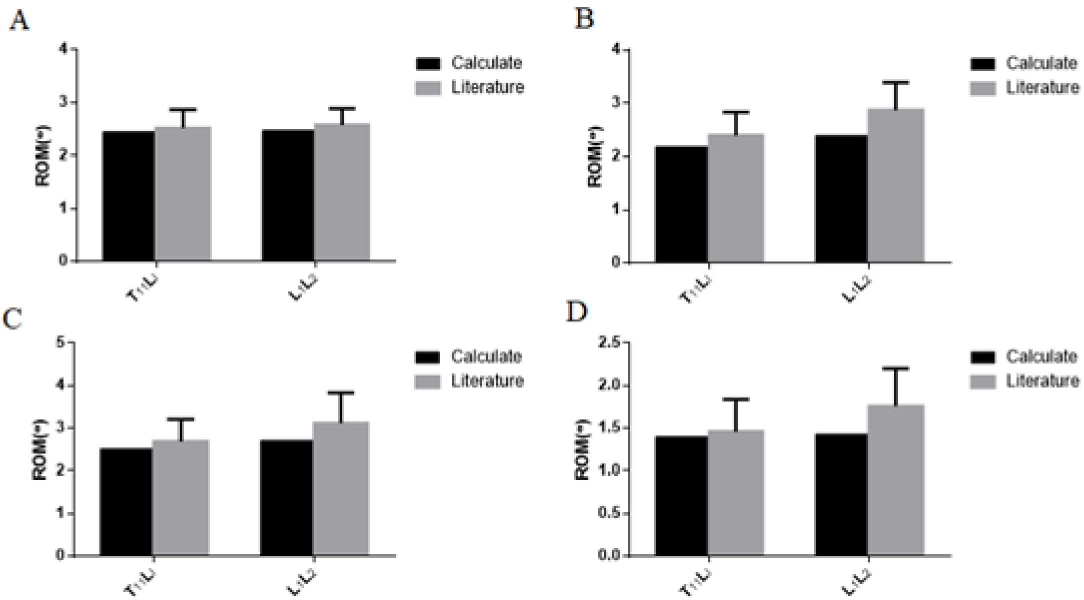

Figure 2

Model and literature ROM comparison

Notes：A：Anteflexion ROM; B:Backward extension ROM; C:Side bend ROM; D:Rotate ROM

Statistics of the maximum stress values of four groups of models

Image not available with this version

Figure 3

This image is not available with this version.

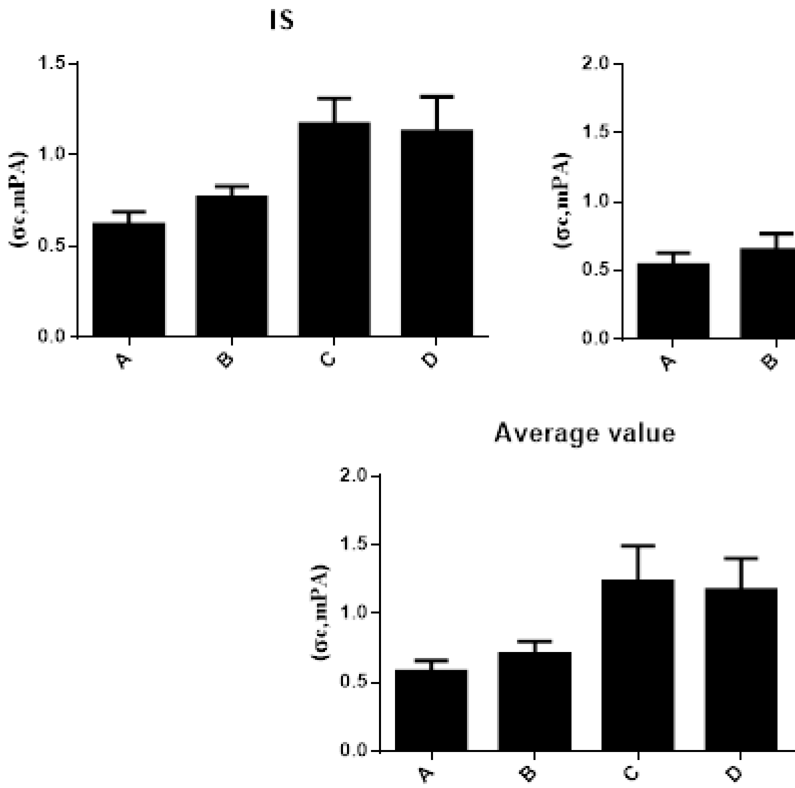

Figure 4

Axial Compression strength of four treatment methods for Thoracolumbar fracture(σc,

,mPA)

Notes�A�Conservative treatment group�B Open surgical treatment group�C�PKP group�D�PVP group.

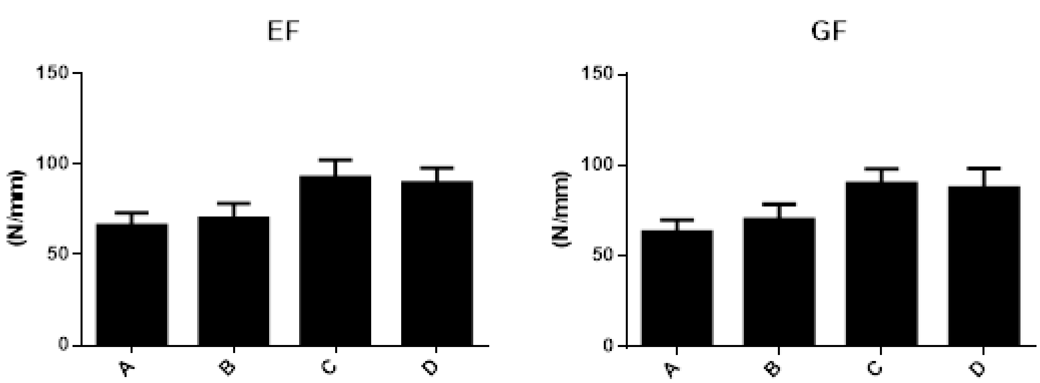

Figure 5

Stiffness of four treatment methods for thoracolumbar fracture(N/mm,) Notes：A：Conservative treatment group，B Open surgical treatment group，C：PKP group，D：PVP group.