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ORIGINAL ARTICLE

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The relationship between vertebral body deformity and disc degeneration in lumbar spine of the senile

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Abstract This study provides an investigation of the relationship between vertebral deformities and disc degeneration in patients with senile osteoporosis using biomechanical and medical imaging methods. The finite element analysis showed that stress concentration in the central area of the vertebral body is much decreased with disc degeneration, indicating that load transmission has been altered. Radiography and MRI suggested that vertebral deformities are related to the height and degeneration of the disc just below this vertebral body. When a disc has decreased height or degeneration, the vertebral body just above it is less likely to be deformed for patients with spinal osteoporosis.

Key words Lumbar vertebrae · Osteoporosis · Spinal fractures · Intervertebral disc

Introduction

Spinal osteoarthritis and osteoporosis are age-related degenerative conditions, and their incidences rise as the population ages. It has been generally accepted that both conditions are different diseases and are possibly due to different pathomechanisms. Although both are common, they coexist rarely. Patients with osteoarthritis usually have no significant loss of bone mass, while osteoporotic patients present with a low bone mass [9, 22]. In previous study [7], we compared the degrees of osteoporosis and osteoarthritis in Chinese elderly patients with spinal osteoarthritis and osteoporosis, and in normal controls. The results also suggested that osteoarthritis is inversely related to osteoporosis.

Compression fractures of the vertebral body are one of the most common fractures in patients with osteoporosis [5]. The risk for this fracture is not only associated with decreased bone mass, but also possibly affected by the structure and function of intervertebral disc. The relationship between osteoporotic fractures of the vertebral body and intervertebral disc has been seldom documented. The aim of this study is to investigate the relationship between vertebral deformities and disc degeneration in patients with senile osteoporosis using biomechanical and medical imaging methods.

Materials and methods

Finite element analysis

A three-dimensional finite element model of a lumbar motion segment consisting of two adjacent vertebrae and the intervertebral disc, apophysial joints and ligaments was developed [3]. This model was simplified as a half structure for analytic convenience (Fig. 1), with a total of 388 nodes and 293 elements. Table 1 gives the details of this model.

The external load was evenly distributed across the upper surface of model. An axial compression of 1200 N, alone or coupled with a sagittal moment of ± 30 Nm, was applied to simulate lumbar spine in upright, flexion, or extension position, respectively.

Young’s modulus of the annulus fibrosus was considered to be 92 MPa, and Poisson’s ratio 0.45. The internal pressure of the nucleus was 1.5 times the axial compression stress. When disc degeneration was simulated, Young’s modulus and Poisson’s ratio of the annulus fibrosus were considered to be 31 MPa and 0.45, respectively, with an internal pressure of the nucleus 1.1 times the axial compression load.

Stress states were expressed as effective stress, and results were analyzed focusing on the stress distribution of trabeculae in the vertebral body.

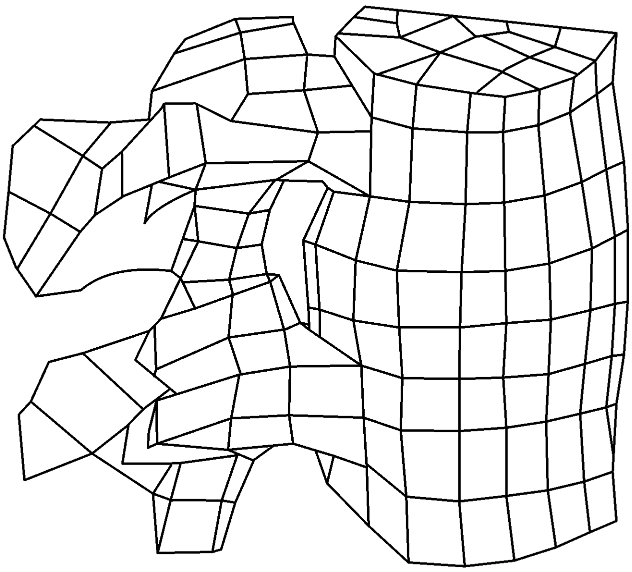

Fig. 1 Three-dimensional finite element model of lumbar motion segment

Table 1 Constants in this model

Components	Young's modulus (MPa)	Poisson's ratio
Cortex	12480	0.25
Trabeculae	345	0.20
Annulus Fibrosus	92	0.45
Apophysial Joint	24.3	0.40

Radiography and MRI

Patients

Eighty-three senile osteoporotic Chinese patients with vertebral compression fractures in the lumbar spine were studied in this series. There were 27 men and 56 women, with an age range of 60–84 years (mean age, 72.4 years).

Normal controls

Sixty-one normal subjects were randomly selected as the controls, with an age range of 60–77 years (mean age, 71.8 years). They had no significant back pain and no history of spinal fracture.

Radiographic assessment

Lateral radiographs of lumbar spine of all patients and controls were obtained. From these radiographs, anterior (H*a*), middle (H*m*), and posterior (H*p*) heights of vertebral bodies were measured, and then the ratios, H*a*/H*p*, H*m*/H*p*, and H*p*/H*p* from L1 to L5 were calculated [8, 10]. The vertebral fractures were identified and the severity of deformity was graded [11] by deviation, in standard deviation (SD), from the normal values specific to each vertebral level [6]: grade 1, <2 SD (normal); grade 2, 2–<3 SD; grade 3, 3–<4 SD; and grade 4, ≥4 SD. Cases in which multiple vertebral bodies were involved were classified as the most severe deformity. Thereafter, anterior and posterior heights of the intervertebral disc just below the fractured body were measured, and a decrease in disc height was recorded when the average height had decreased by more than 2 SD compared with the normal values.

MRI

Among patients with fractures, the MRI study was performed in 25 patients on an MT/S 0.35-T superconductive unit (Diasonics). Using a spin echo sequence of 1500/80 ms (T_R/T_E) and a slice thickness of 5 mm, T2-weighted midsagittal images were obtained to evaluate the degree of disc degeneration using the five-grade scale of Gibson et al. [12] and Mehalic et al. [17], namely: grade 0, very intense; grade 3, intense; grade 2, moderate; grade 4, slight; grade 5, none. Furthermore, we defined grade 0 as normal, grades 1 and 2 as mild and moderate disc degeneration, and grades 4 and 5 as severe disc degeneration.

Follow-up

All patients were treated conservatively and followed up between 1 and 7 years. The heights of fractured vertebral bodies, old or fresh, and of the intervertebral discs [13] just below these vertebral bodies were measured on lateral lumbar spine radiographs for 34 of these patients at the latest follow-up. The duration of follow-up for these patients was between 5 and 7 years. Height ratios of vertebral bodies and discs at follow-up to at the first diagnosis was calculated.

Results

Finite element analysis

Stress levels

Table 2 shows the mean values of stress levels in the lumbar spine components. Although the stresses were presented numerically, they are merely quantitative values. After disc degeneration, the stress level is decreased in the anterior element such as cortical and trabecular bone of the vertebral body, end plate, and annulus fibrosus, while that in the posterior element, including arch pedicle, interarticularis, and apophysial joints, is increased.

Table 2 Average stress (MPa) in the lumbar spine with normal and degenerative disc (*U* upright, *F* flexion, *E* extension)

Components	Normal Disc			Degenerative Disc		
	U	F	E	U	F	E
Cortex	0.87	1.49	1.26	0.78	1.24	0.81
Trabeculae	9.18	20.37	24.03	8.77	18.87	23.18
End plate	2.68	4.75	5.17	3.43	4.01	4.87
Annulus fibrosus	1.16	1.34	1.64	0.87	0.47	0.67
Arch pedicle	4.16	4.05	10.69	4.57	4.62	5.25
Interarticularis	1.65	1.65	4.43	2.41	2.99	5.76
Apophysial joint	1.50	1.15	4.13	2.26	2.53	5.19

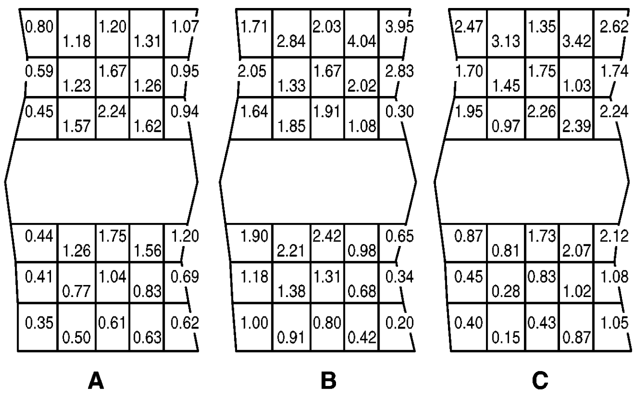

Fig. 2 Stress distribution of trabeculae with normal disc (midsagittal plane, *left* anterior, *right* posterior). *A* upright, *B* flexion, *C* extension

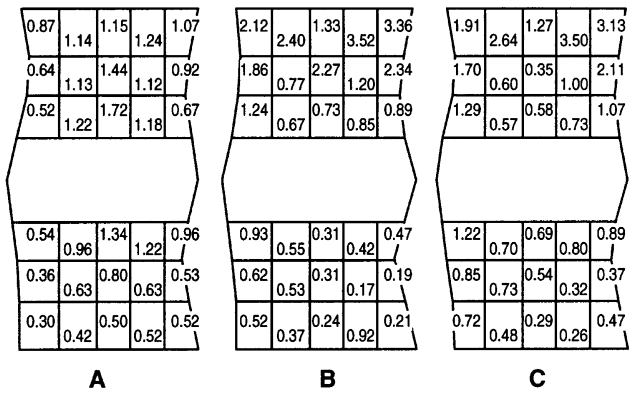

Fig. 3 Stress distribution of trabeculae with degenerative disc (midsagittal plane, *left* anterior, *right* posterior). *A* upright, *B* flexion, *C* extension

Stress distribution

With normal disc, stress is concentrated in the central part of the vertebral body adjacent to the end plate when the lumbar spine is positioned in any of the three postures (Fig. 2). When disc is degenerative, however, the stress distribution is significantly changed. Stress levels in the trabecular bone of the vertebral body tend to be more even: the stress is decreased in the central part while the peripheral part has a relatively higher level (Fig. 3).

Radiography and MRI

Vertebral deformities and disc heights

Of 61 normal controls, vertebral deformities were observed in 11 and decreased disc heights in 34, with only 2 showing a height decrease in the disc just below the deformed vertebra. Decreased disc height was demonstrated in 23 patients, but only two of these discs were located just below the deformed vertebra.

The χ^2 test was used to analyze statistical differences. Osteoporotic patients showed significantly more deformed vertebral bodies ($\chi^2 = 100.635$, $P < 0.01$) than controls, but these patients had significantly fewer discs of decreased height ($\chi^2 = 10.406$, $P < 0.01$).

Vertebral deformities and the degree of disc degeneration

Among the 25 patients on whom MRI examination was performed, deformity of vertebral body was graded as grade 2 in 15, grade 3 in 7, and grade 4 in 3. From the MR images of these patients, the degree of degeneration of related discs was identified as grade 0 in 9, grade 1 in 12, grade 3 in 1, and grade 4 in none.

Height ratios of vertebral bodies and discs

In the 34 patients followed up, the height ratios of vertebral bodies and discs were 0.82 ± 0.20 (mean ± SD) and 1.12 ± 0.31, respectively, for the old fractured vertebrae. Seven patients were found with fresh fractures; their mean disc height ratio was 1.07 ± 0.14.

Discussion

Pathologically characterized with decrease and/or thinning of trabeculae and thinning of cortical wall, spinal osteoporosis leads to a decrease in the load-bearing capacity of vertebral bodies so that compression fractures occur easily. These fractures are different from those usually seen in limbs: many patients have no significant back pain nor even typical clinical symptoms. In a clinical study of 247 patients with spinal osteoporosis we performed previously [4], only 193 of them (78.5%) had back pain. This finding indicates that vertebral compression fractures may be the only clinical presentation in spinal osteoporotic patients. Compressive deformity demonstrated by radiography as an indicative sign for diagnosis of vertebral compression fractures is simple, effective, and used commonly. Once height or height ratio of the vertebral body is below the normal range, vertebral compression fracture may be diagnosed. Controversies exist on radiographic measurements of vertebral body height, with various criteria for measurement being developed. In this study, the normal value of vertebral body height from measurement of normal Chinese controls was used as the criterion, so the results are reliable.

Degeneration of intervertebral disc usually means a series of changes in biochemical and histological composition of the annulus and nucleus pulposus. These changes will impair the mechanical properties and functions of the disc, thereby disrupting orderly events of physiology.

Nachemson [18] predicted that disc degeneration would be followed by a transfer of compressive stress from the nucleus to the annulus. This theory has been recently confirmed by Adams et al. [1]. In their investigation, increase of compressive stress peaks within the annulus fibrosus was noted along with decrease of compressive stress peaks in the nucleus. Furthermore, disc degeneration will have a more important effect upon the adjacent vertebral body [19], though their properties are interdependent [16]. In a previous study [7], we found that osteoarthritis is inversely related to osteoporosis in the spine. Osteoarthritis may retard the occurrence of osteoporosis, while osteoporosis may prevent or relieve osteoarthritis. From present study, it is suggested that vertebral deformity in osteoporotic patients is determined by height and degree of degeneration of the intervertebral disc just below this body. In fact, a reduction of disc height and subsequent decline in the length of the spine is associated with age-related degeneration in the disc [2, 20, 21]. When a disc is of normal height or of no degeneration, the vertebral body just above it is more likely to be deformed for patients with spinal osteoporosis. However, if patients have their disc thinned or degenerated, the vertebral body just above the disc will be less susceptible to fracture. Satisfactory explanations have been lacking for this phenomenon. Hansson and Roos [14] performed a biomechanical study in which they classified vertebral body fractures into central fractures adjacent to end plate with high bone mineral content surrounded by normal discs and peripheral fractures or wedge fractures with lower bone mineral content and degenerative disc. They believed that the degree of disc degeneration did not directly affect the ability of the vertebral body to resist fractures. In contrast, this study shows that in vertebral bodies with a healthy disc there was a higher stress area at the trabeculae and end plate interface, but with disc degeneration there was decreased stress in this area, relatively higher stress at the periphery, and increased stress in the posterior element. So we conclude that with disc degeneration the path of load transmission in the lumbar spine is altered, and dysfunction of disc will decrease the load borne by the vertebral body above the disc. Therefore, the risk for compression fracture in this vertebral body is much decreased compared with the risk in those adjacent to normal disc, even though osteoporosis has decreased the strength of the vertebral body. Recently, lumbar spine under cyclic compression demonstrated more microfractures of trabeculae after discectomy than in controls in an animal cadaveric experiment [15]. Since this experiment was performed in vitro, the implications of these results need further analysis.

From the follow-up data, not only did seven patients have fresh vertebral fractures, but the heights of the deformed vertebral bodies were further decreased. Restoration of the heights of the deformed vertebrae should be a central aim in clinical management of osteoporotic fractures, and is important in the relief or avoidance of spinal deformity and back pain. The increase in disc height ratio accompanying the decrease in vertebral height ratio is likely due to concaved end plates when vertebrae are fractured. Height ratio is helpful in dynamically observing the results and prognosis after therapy as well as diagnosing vertebral compression fracture.

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