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The positive correlation between upper adjacent vertebral fracture and the kyphosis angle of injured vertebral body after percutaneous kyphoplasty: An in vitro study

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ABSTRACT

Objective: To investigate the correlation between the kyphosis angle of injured vertebral body and the risk of upper adjacent vertebral fracture after percutaneous kyphoplasty (PKP) using an osteoporotic vertebral compressed fracture model.

Materials and methods: 24 functional spinal units (FSUs, T9 to L4) were selected from 6 elderly formalin preserved vertebral specimens to build the vertebral compressed fracture model. According to the kyphosis angle between the upper plate of upper vertebral body and the horizontal plane, group A (0°) and group B (20°) were defined, with each group comprised with 12 FSUs. The stiffness and fracture load were measured in both groups.

Results: After PKP, the stiffness was (571.513 ± 83.373)N/mm and the fracture load was (1751.659 ± 112.291)N in group A, with both significantly higher than those of group B (stiffness, (307.706 ± 46.723)N/mm; fracture load, (1128.011 ± 125.417)N).

Conclusions: To reduce the risk of upper adjacent vertebral fracture, it is better to restore the height of injured vertebral body and decrease the angle of kyphosis to increase the capability of upper adjacent vertebral body against fracture.

1. Introduction

With the aging of the global population, the incidences of osteoporosis increase every year. Meanwhile, the number of patients with osteoporotic vertebral compression fracture (OVCF) is growing, which is often accompanied with lower back pain and restrained activities. To relieve the pain caused by OVCF, bone cement is injected to the injured vertebral body by percutaneous kyphoplasty (PKP), which decreases the mortality rate of elder patients. PKP-related complications are major concerns during its clinical application, with one of which being the new adjacent vertebral fracture. The notions are still conflicting as to the reason behind the new upper vertebral fracture after PKP [1–3]. We propose that it may be due to the detrimental kyphosis angle of injured vertebral body after the procedure. The injured vertebral body becomes wedge-shaped and shows the kyphosis deformity, which caused the vertical load to shift to the front of vertebral body [4]. Combined with pre-existing osteoporosis, slight force may cause new adjacent vertebral fracture [5].

Thus, we designed an experimental model to simulate the mechanics of this course of vertebral compression. By controlling the kyphosis angle of injured vertebral body during PKP, the biomechanical characteristics of upper adjacent vertebral body was evaluated. In the meantime, the correlation between the kyphosis angle of injured vertebral body and the risk of upper adjacent vertebrae fracture was investigated.

2. Materials and methods

2.1. Materials

Full thoracic vertebrae (T)-9 to lumbar vertebrae (L)-4 and their subsidiary structure were collected from six female elder specimens soaked in formalin for three months (Department of Anatomy, Medicine School of Ningbo University) [6], excluding the ones with obvious damage, spinal deformities and tumors. The age of the subjects was 70–79 years old, with the average being 73.3. Accessory structures were removed, except for the vertebral

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Table 1
Specimens information.

No.	Gender	Age	BMD T value	Group	
				A (0°)	B (20°)
1	Female	71	−4.2	T9-10	T11-12
				L1-2	L3-4
2	Female	74	−4.6	T11-12	T9-10
				L3-4	L1-2
3	Female	74	−4.7	T9-10	L1-2
				T11-12	L3-4
4	Female	79	−4.3	T9-10	T11-12
				L3-4	L1-2
5	Female	72	−4.5	T11-12	T9-10
				L1-2	L3-4
6	Female	70	−4.3	L1-2	T9-10
				L3-4	T11-12

bodies and intervertebral discs. All specimens were screened by dual energy X-ray absorptiometry test (Table 1) [7].

Two adjacent vertebral bodies and their intervertebral disc were defined as a functional spinal unit (FSU). Therefore, there were four FSUs per specimen, and the lower body was defined as injured vertebral body, with the upper body as adjacent vertebral body.

2.2. Instruments

Digital camera, dual energy X-ray absorptiometry (Discovery, HOLOGIC, USA), General biomechanics apparatus (Model 3366, Instron Corporation, USA), polymethyl methacrylate bone cement (Mendec Spine Resin, Tecres S.P.A, Italy), and PKP surgery instrument (Model 202, Guanlong medical supplies company, China) were used in this study.

2.3. Labeling

Four FSUs from each specimen were divided into two groups: group A and group B. To minimize the influence of the differences between segments, T-9 to L-4 segments were contained in every group, and all were numbered (Table 1). Group A was defined as the ones with the height and kyphosis angle of injured vertebral bodies restored to normal (0°) after PKP. Group B was defined as the ones with the height and kyphosis angle recovered partly (20° kyphosis angle remaining). The front height of the intact injured vertebral body (H), the fractured injured vertebral body before PKP (H_1), and the injured vertebral body after PKP (H_2), and the anteroposterior diameter of the intact injured vertebral body's low end plate (L) were measured by Vernier caliper (precision:0.1 mm) (Tables 2 and 3). The samples packaged in normal saline gauze were sealed in plastic bag, and tested within 24 h.

2.4. Wedge-shaped compression fracture model

Cap-like bone cement cover was made using a mold and placed onto the upper end plate of upper vertebral body and the lower end plate of lower vertebral body to balance the stress to vertebral bodies during compression. The bone cement was mixed thoroughly and then transferred into the mold. The FSU was pressed into the bone cement, and the thickness of cement was about 3–5 mm. To facilitate the stabilization during the process, an impression was made by cylinder-shaped metal bar on the middle of upper end pate, within bone cement cover.

The improved Gepstein modeling approach was applied here [8]. Two holes were made in the middle of injured vertebral body with the 2.5 mm Kirschner wire. The distance between the holes was about 1 cm, which decreased the strength of this area compared to the normal bone. FSU was placed onto the pressure plate of General biomechanics apparatus. The cylinder-shaped metal bar was placed on the front part of FSU, which would be under eccentric load during compression. The preload was 500 N. The front height of lower vertebral body was compressed by 50% at 1 mm/s rate, and the compression model was completed when a fracture line was formed in the middle of lower vertebral body (Fig. 1A). The fracture model was confirmed with X-ray to make sure the imaging characteristics meet the compression fracture standard. Meanwhile, the kyphosis angle between the upper end plate of upper vertebral body and the horizontal plane was calculated by the image software (Table 4).

2.5. Percutaneous kyphoplasty

Injured vertebral body with fracture was treated with standard PKP (Fig. 1B): with puncture through vertebral pedicle, bilateral insertion of needles and balloon dilation. The height of vertebral body height in group A was restored to normal or nearly normal. The expected front height of injured vertebral body (H3) with partial recovery in group B was calculated based on the anteroposterior diameter of injured vertebral low end plate (*L*). The design formula was $H_3 = H\text{-}\sin20^\circ \times L$ (Fig. 3). The front height of injured vertebral body (H_2) was recovered to H_3 in actual operation. 4 ml bone cement was injected per injured vertebral body and the leaking of bone cement was avoided.

Table 2
The height of inferior injured vertebral body and anteroposterior diameter (cm) of group A.

No.	Segments	Initial front height (H)	Anteroposterior diameter (L)	The front height before PKP (H_1)	The front height after PKP (H_2)
1	T10	2.86	2.92	1.44	2.84
	L2	3.28	3.26	1.64	3.24
2	T12	2.56	3.02	1.38	2.54
	L4	2.92	3.46	1.46	2.88
3	T10	3.02	2.88	1.54	2.98
	T12	3.22	3.02	1.68	3.16
4	T10	2.72	3.24	1.40	2.64
	L4	3.44	3.72	1.76	3.44
5	T12	2.34	3.02	1.22	2.32
	L2	2.94	3.12	1.50	2.94
6	L2	2.52	3.34	1.28	2.50
	L4	2.94	3.42	1.34	2.92
		2.90 ± 0.36	3.20 ± 0.25	1.47 ± 0.16	2.87 ± 0.33