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Basic Science

The effect of kyphotic deformity because of vertebral fracture: a finite element analysis of a 10° and 20° wedge-shaped vertebral fracture model

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Abstract

BACKGROUND CONTEXT: Kyphotic deformity associated with vertebral fracture is believed to be a significant risk factor for additional vertebral fractures. However, previously published research is limited.

PURPOSE: The purpose of this study was to estimate the biomechanical stresses that kyphotic deformity, with an initial vertebral fracture, place on adjacent vertebrae using three-dimensional finite element (FE) of the spine, head, and ribs.

STUDY DESIGN: This study is based on the basic science.

METHODS: Total Human Model for Safety, a three-dimensional FE model of the human body, was used and adjusted to represent an elderly osteoporotic woman. The 12th thoracic vertebra (T12), which is a frequent site of osteoporotic vertebral fractures, was transformed to a wedge shape at 0°, 10°, and 20° to create a normal model, a 10° kyphosis model, and a 20° kyphosis model. Additionally, compensated postures were created for the 10° and 20° kyphosis models. Thus, five models were created: (A) a normal model, (B) a 10° kyphosis model, (C) a 20° kyphosis model, (D) a 10° kyphosis model with compensated posture, and (E) a 20° kyphosis model with compensated posture. Compressive principal stresses (CPSs) on T1–L5 in each model were calculated.

RESULTS: The highest CPS value was 7.78 MPa placed on the anterior part of the T10 vertebra in the 20° kyphosis model. In the 20° kyphosis model, the higher CPS values showed bimodal peaks at T6 and T7 in the midthoracic spine and at T10 and T11 in the two superior adjacent vertebrae. The maximum CPS values in the A, B, C, D, and E models at T10 were 3.12, 6.74, 7.78, 6.61, and 5.78 MPa. At T11, they were 1.70, 4.41, 6.45, 4.07, and 4.79 MPa.

CONCLUSIONS: The existence of an initial vertebral fracture at T12 caused an increase in stress on adjacent vertebrae. Higher CPS values showed bimodal peaks in midthoracic vertebrae and in two superior adjacent vertebrae when T12 was trans

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formed to a wedge shape in the 20° kyphosis model.

Keywords: Osteoporotic vertebral fracture; Kyphotic deformity; Finite-element analysis; Biomechanics; Whole human model; Bimodal peaks

Introduction

Osteoporosis in the elderly has become a major public health problem, and vertebral fracture is one of the most important clinical manifestations in spinal osteoporosis [1]. Vertebral fractures lead to spinal deformities, loss of height, chronic back pain, changes of mood, and an overall impairment in the quality of life [2–4]. Also, reduction of pulmonary function [5,6] and gastroesophageal reflex disease [7] are correlated significantly with spinal kyphotic deformity because of vertebral fractures. Furthermore, all vertebral fractures that are symptomatic or radiographically identified are associated with increased mortality [8,9].

In clinical practice, once a vertebral fracture has occurred, another fracture at an adjacent level becomes likely. Also, recent evidence suggests that initial vertebral fracture has been associated with the increased risk of subsequent fracture for another vertebrae [10–13]. Klotzbuecher et al. [11] reported that women with preexisting vertebral fractures had approximately four times greater risk of subsequent vertebral fractures than those without previous fractures. It would appear that many factors, for example, bone mineral density (BMD) and bone quality, are correlated with additional vertebral fractures, but the risk remains even after medication for the correction of BMD [13]. Therefore, a preexisting vertebral fracture indicates potent risk for further vertebral fracture in itself. Although kyphotic deformity after vertebral fracture has some bearing on subsequent adjacent-level fractures, evidence from previous research has been limited. Therefore, the purpose of this study was to estimate the biomechanical stresses that initial vertebral fracture place on other vertebrae in the kyphotic spine using finite element (FE) analysis.

Materials and methods

Construction of the whole-body FE model with a T12 vertebral fracture was completed, using the Total Human Model for Safety (THUMS, Toyota Technical Development Corporation, Aichi, Japan), which is a three-dimensional FE model of the human body [14]. Mobile spine, head, and ribs were extracted from THUMS. The model was adjusted to represent an average-sized elderly Japanese woman. The height and weight were set at 150 cm and 50 kg. The thickness of the cortical shell was configured for 0.3 mm in view of osteoporosis [15]. The material properties of this analytic model were the same as those used in THUMS (Table). T12, which is a frequent site of osteoporotic vertebral fractures, was transformed to a wedge shape at 0°, 10°, and 20° to create a normal model, a 10° kyphosis model, and a 20° kyphosis model. Additionally, compensated postures were created for the 10° and 20° kyphosis models. In the compensated postures, kyphosis models were retroversed around the center of the fifth lumbar vertebra (L5) to the point that the line of the center of T1–L5 became perpendicular to the ground. Thus, five models were created: (A) a normal model, (B) a 10° kyphosis model, (C) a 20° kyphosis model, (D) a 10° kyphosis model with compensated posture, and (E) a 20° kyphosis model with compensated posture (Fig. 1).

Table
Material properties in the FE model

Part of the model	Young modulus (MPa)	Poisson ratio
Cancellous bone		
C1–C7	70.00	0.300
T1–T12	203.0	0.450
L1–L5	70.00	0.450
Rib	40.00	0.450
Cortical bone		
C1–C7	5,000	0.300
T1–T12 (front)	5,000	0.300
T1–T12 (rear)	4,000	0.300
L1–L5	1,000	0.450
Rib	18,900	0.300
Rib cartilage	24.50	0.400
Cartilage	12.60	0.400
Annulus in annulus out	0.200	0.400
Annulus out	13.30	0.400
Nucleus pulposus		
C1–C7	0.198	0.499
T1–T12	0.200	0.499
L1–L5	0.013	0.499
Vertebral end plate	500.0	0.400
Cartilaginous end plate	24.00	0.400
Brain	0.102	0.499
Lamina	8,000	0.220
Diploe	200.0	0.220
Face	5,540	0.300
Iliolumbar ligament	10.00	0.300
LCL and SCL	52.00	0.300
SSL, ISL, LF, and ITL	10.00	0.400
ALL and PLL	20.00	0.220
ALL and PLL (cervical)	3.250	0.220
LN (C2–C7)	3.010	0.450

ALL, anterior longitudinal ligament; FE, finite element; ISL, interspinous ligament; ITL, intertransverse ligament; LCL, lateral costotransverse ligament; LF, ligamentum flavum; LN, ligamentum nuchae; PLL, posterior longitudinal ligament; SCL, superior costotransverse ligament; SSL, supraspinous ligament.