Dynamic spine hyperflexion is related to vertebral compression fractures in postmenopausal women

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Abstract

Background: Previous studies on osteoporotic vertebral fractures are usually based on the neutral posture of the spine; however, the fractures are usually associated with the curvature of the spine. Therefore, we aimed to ascertain the relationship between vertebral compression fractures and thoracolumbar hyperflexion Cobb angles (TLHCobb) and determine the clinical cut-off of the TLHCobb angle.

Methods: In this retrospective case-control study, TLHCobbs were collected from 154 postmenopausal women with thoracolumbar fractures (study group) and 310 postmenopausal women with lumbar instability or spondylolisthesis (control group). Demographic data, clinical data, and quantitative computed tomography (QCT) findings were compared between the groups. Chi-squared tests and unpaired *t*-tests were used to assess the group characteristics and proportions. Logistic regression was used to examine the association between vertebral compression fractures and TLHCobb.

Results: Fracture prevalence was higher in the higher TLHCobb study group than that in the control group [OR = 2.81 (2.15–3.67)] after adjusting for age, BMI, and QCT findings. TLHCobbs at and $> 20.05^\circ$ were associated with an increased fracture prevalence and ORs of 2.79 (1.82–4.27) and 4.83 (3.24–7.20), respectively. TLHCobb and QCT values differed between the study and control groups ($p < 0.001$ for both). There were no significant differences in body mass index (BMI), disk height, or coronal TLHCobb between the two groups.

Conclusion: There was an association between the prevalence of vertebral compression fractures and TLHCobbs in postmenopausal women, and a TLHCobb $> 20.05^\circ$ can be an indicator of vertebral fracture.

Background

Many efforts have been made to prevent osteoporotic fractures in postmenopausal women, from clinical imaging to exercise programs and drug therapy. Identifying those at high risk of osteoporotic fractures is worthwhile, especially when it can be conveniently achieved by routine imaging examinations.

The relationship between spinal curvature and bone mineral density (BMD) in postmenopausal women is commonly observed; however, excessive spine curvature, such as thoracic or thoracolumbar hyperkyphosis, is significantly associated with a high risk of vertebral fracture [1–3]. Age-related hyperkyphosis accelerates degenerative disc disease, especially in the anterior fibers of the annulus fibrosus [4]. Disc narrowing is also significantly associated with an increased risk of vertebral fracture [5]. Therefore, spinal hyperflexion and vertebral fractures may be mutually causal.

A neutral spine posture is usually used in the study of osteoporotic spine curvature, and radiographic evidence of thoracic kyphosis, lumbar lordosis, and thoracolumbar curvature have demonstrated an association between fractures and spinal curvatures [1, 6–8]. Thoracic or thoracolumbar lateral radiography provides a method of assessing the risk of vertebral compression fracture in a neutral spine posture in postmenopausal women, but these lack an accurate posture imitation for vertebral fracture.

However, the flexion-lumbar posture is more common in low-energy spine injuries than the neutral lumbar posture [9, 10]. In most falldown cases, the lumbar spine tends to move from a neutral posture to flexion or hyperflexion postures because of the joint action of the upper body, hip, and the center of gravity in front of the thoracolumbar segment (Fig. 1). Therefore, lumbar flexion postures may have varying degrees of simulation of the spinal situation in these fractures [11].

The thoracolumbar spine (T10–L2) is the junction of the lumbar and thoracic vertebrae. T11–L2, as a spinal transition region in anatomy and mechanics, has the highest incidence of vertebral deformity and fracture, particularly in women after menopause [12, 13]. Hyperflexion and neutral lumbar X-rays provide two types of information: the thoracolumbar hyperflexion Cobb angle (TLHCobb), and the range of forward flexion of the thoracolumbar spine. Lumbar hyperflexion imitating the posture of most spinal injuries may contribute to determining the risk of vertebral fracture, of which the TLHCobb, an indicator of the highest incidence of vertebral fracture, could be a radiographic reference for a vertebral compression fracture. In this study, we aimed to ascertain the relationship between vertebral compression fractures and TLHCobbs as well as determine the possible clinical TLHCobb cut-off degree.

Figure 1A neutral spine posture is relatively static and persistent (A). A dynamic and transient hyperflexion posture (B) under compression shows the stress process of most low-energy vertebral fractures. The TLHCobb is the key indicator for this process.

Materials And Methods

Subjects

This was a retrospective and single-center study with data collected from postmenopausal women (study group and control group) treated at Chinese PLA General Hospital from June 2017 to July 2019. The study group consisted of osteoporotic patients with vertebral compression fractures at the thoracolumbar junction (T11–L2) and vertebroplasty. The inclusion criteria were (i) vertebral compression fracture of low energy (fall from standing height or a lower position and sneeze), (ii) first and only one vertebral body fracture in T11–L2, and (iii) treatment with vertebroplasty. The exclusion criteria were as follows: a tumor, high-energy fracture, spinal scoliosis (Cobb angle $> 10^\circ$), and lack of information on standing and erect lumbar hyperflexion X-ray. The control group was age-matched (unpaired t -test, $p > 0.05$) patients with lumbar instability or spondylolisthesis (Meyerding I) verified by lumbar hyperflexion X-ray, excluding patients with spinal tumors, ankylosing spondylitis, inflammatory spondylitis, congenital spinal deformity, spinal scoliosis (Cobb angle $> 10^\circ$), and a previous history of fracture in T11–L2. The study was approved by the Human Ethics Committee of Chinese PLA General Hospital. All participants were informed about the study and they signed a written consent for inclusion.

Data collection

Age, weight, body mass index (BMI; kg/m^2), and other information of the two groups were recorded on admission. Radiographs of hyperflexion, neutral lateral, and neutral anteroposterior lumbar vertebrae

were collected. Data on fracture site, Cobb angle, and disc height in T11–L2 were recorded and calculated.

The TLHCobb was drawn by two lines parallel to the superior endplate of T11 and the inferior endplate of L2 on a hyperflexion lumbar radiograph. Accordingly, the thoracolumbar Cobb angle was measured on a neutral lateral radiograph. The Cobb angle formed on the ventral side was classified as positive, and on the dorsal side as negative. The TLHCobb before fracture was retrospectively assessed by calculating the difference between the post-operation TLHCobb and the Cobb angle change of the fractured vertebra [1]. The pre-fractured Cobb angle of the vertebrae was calculated on the average Cobb angle of the non-fractured vertebrae at the same position in the same group [14]. The postoperative difference in the thoracolumbar Cobb angle between the hyperflexion and neutral postures (DTLCobb) was collected (Fig. 2).

Fig. 2 DTLCobb is the difference between neutral spine posture in A and hyperflexion spine posture in B: $DTLCobb = TLHCobb.p - TLCobb.p$

The maximal region of the cancellous bone was manually drawn in the middle cross-section of the vertebral body (Fig. 3). The mean of two intact vertebrae in T12–L3 was selected to represent the density of the cancellous bone [15]. The density of the fractured vertebra before fracture was calculated by the mean density of the adjacent vertebrae (the upper and the lower of fractured vertebra) [16]. BMD was classified as normal ($BMD > 120 \text{ mg/cm}^3$), osteopenia ($80\text{--}120 \text{ mg/cm}^3$), and osteoporosis ($BMD < 80 \text{ mg/cm}^3$) according to the criteria of the World Health Organization and the American College of Radiology (ACR) [17]. BMD was measured using a QCTP_{RO}2.0 workstation (Mindways Software Inc., Austin, TX, USA) and quantitative computed tomography (QCT) scans in a 16-slice spiral CT scanner (GE Discovery CT750 HD) with the following parameters: 120 kV, 125 mA, pitch 0.985, SFOV 500 mm, aperture 1.25mm, and table height 780 mm.

Fig. 3 The region of interest (ROI) was defined as the largest ellipse in vertebral cancellous bone in the axial position. It has been found that taking the largest ellipse can make the value of the vertebral body BMD more stable and reduce the influence of local hyperplasia and sclerosis in the vertebral body on the BMD value.

Statistical analysis

Data were analyzed using SPSS version 26 (IBM, Chicago, IL, USA). Descriptive statistics for continuous variables were expressed as means and standard deviations). Differences in age, BMI, QCT findings, and Cobb angles between the two groups were assessed using chi-squared and unpaired *t*-tests. The association between vertebral compression fracture and TLHCobb was examined using logistic regression analysis. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated using multivariate logistic regression analysis of age, BMI, and QCT findings. The cut-off of the TLHCobb was determined by a receiver operating characteristic (ROC) curve and Youden's index.

Results

A total of 205 patients with a vertebral compression fracture were treated according to the inclusion criteria, of which 154 patients were included in the study group per the exclusion criteria. There were 23 T11 (14.9%), 47 T12 (30.5%), 53 L1 (34.4%), and 31 L2 (20.1%) compression fractures. Altogether, 355 patients were treated for lumbar instability or spondylolisthesis, of which 310 patients were categorized as the control group based on the exclusion criteria.

Despite the lack of differences in age, BMI, disk height, and Average Cobb between the two groups ($p > 0.05$), the QCT values in the study group were lower than those in the control group ($p < 0.001$). The Cobb angles and BMDs of the thoracolumbar spine were significantly different between the pre-fracture and control groups (Table 1).

Table 1
Baseline characteristics and research indices of study subjects (n = 464)

Variables	Study group (n = 154)	Control group (n = 310)	p value
Age (year)	67.45 ± 6.68	66.57 ± 8.22	0.218
BMI (kg/m ²)	25.15 ± 3.43	25.47 ± 3.00	0.302
Disc height (mm)	8.19 ± 1.34	8.34 ± 1.48	0.278
Cobb angles, n	5.53 ± 2.31°(131)	5.17 ± 2.55°	0.165
T11	5.72 ± 2.40°(107)	5.30 ± 2.46°	0.127
T12	5.74 ± 2.23°(101)	5.21 ± 2.61°	0.068
L1	4.28 ± 2.40°(123)	3.89 ± 2.40°	0.129
L2	5.29 ± 2.34°(462)	4.89 ± 2.50°	0.104
Average Cobb			
BMD (mg/cm ³), n			
T11	66.06 ± 22.91(131)	94.56 ± 22.71	< 0.001
T12	67.84 ± 23.79(107)	92.80 ± 24.27	< 0.001
L1	71.20 ± 24.25(101)	91.17 ± 25.93	< 0.001
L2	75.76 ± 25.63(123)	89.29 ± 27.60	< 0.001
Average BMD	70.18 ± 23.99(462)	91.95 ± 25.06	< 0.001
TLCobb angles (°)			
TLHCobb	20.00 ± 5.02	15.62 ± 4.18	< 0.001
DTLCobb	7.29 ± 2.83	8.42 ± 2.40	< 0.001
TLCobb	12.70 ± 6.84	7.19 ± 6.01	< 0.001
Coronal TLCobb	0.76 ± 3.75	1.06 ± 3.69	0.419
* BMI body mass index, BMD bone mineral density, TLHCobb thoracolumbar hyperflexion Cobb angle, DTLCobb is the difference of thoracolumbar Cobb angle between hyperflexion posture and neutral posture			

Figure 4 Angles of 14.85° and 20.05° were determined using the ROC curve and Youden's index

The prevalence of vertebral compression fracture was found to be significantly associated with TLHCobbs. Cut-off values of 17.05° were determined by the ROC curve and Youden's index (Fig. 4), with relevant OR = 2.81 (2.15–3.67). TLHCobbs were classified into mild (TLHCobb < 14.85°), moderate

(TLHCobb 14.85–20.05°), and severe subgroups (TLHCobb > 20.05°). The fracture in both the moderate subgroup (BMD = 82.71 ± 9.25 mg/cm³) and the severe subgroup (BMD = 49.05 ± 14.17 mg/cm³) was significantly more prevalent than in the mild subgroup (BMD = 101.86 ± 13.16 mg/cm³), with OR = 2.79 (1.82–4.27) and OR = 4.83 (3.24–7.20), respectively. DTLCobbs were $9.88 \pm 2.79^\circ$ in the mild subgroup, $7.81 \pm 2.14^\circ$ in the moderate subgroup, and $5.96 \pm 2.62^\circ$ in the severe subgroup.

Discussion

Previous studies have found a correlation between spinal curvature and osteoporotic fractures in a variety of spinal neutral postures. Our results show that in the spinal hyperflexion posture, there is still a correlation between these and a cut-off value with relatively high correlation strength [17.05° and OR = 2.81 (2.15–3.67)].

Vertebral morphology is highly predictive of thoracic kyphosis and thoracolumbar kyphosis, but vertebral body deformity is not necessarily associated with disc degeneration [18]. With aging, changes in the tissue properties of the disc, including dehydration and reorganization of the nucleus pulposus and fragmentation and stiffening of the annulus fibrosus, markedly alter the mechanics of load transfer in the spine [19]. Intervertebral disc gradually changes from a “fluid like” behavior to a more “solid like” behavior with degeneration [20]. The stress gradually spreads over the annulus fibrosus from the nucleus pulposus due to the decline in the hydrostatic pressurization of the nucleus pulposus [21]. Disc morphometry is altered to accommodate changes in the vertebral body shape by extruding into the concave endplate along with disc thinning [22], as was observed in our study. The mechanical interactions of the disc and vertebrae indicate that the increased fracture risk of an osteoporotic spine segment may be slightly counterbalanced by the material consequences of disc degeneration [21, 23]. Disc morphology may be associated with the flexion buffer. Therefore, in postmenopausal women, the flexion effect of the hyperflexion lumbar posture is similar to the compression effect produced by the interaction of degenerating intervertebral discs and osteoporotic vertebral bodies during falls.

The association between increased thoracic kyphosis and future falls is generally accepted [2, 24]. The increased risk of falls in older adults with hyperflexion may be a consequence of a balance deficit, increased postural sway, wider stance, and reduced gait speed [25–27]. In terms of mechanism, this result may be partly related to the decrease in spinal mobility. A study suggests that a lumbar lordosis angle of less than 3° is significantly associated with falls [18]. In this study, a reduction in thoracolumbar motion range was observed in the osteoporotic fracture group. DTLCobbs tended to decrease from the mild subgroup ($9.88 \pm 2.79^\circ$) to the moderate subgroup ($7.81 \pm 2.14^\circ$) and the severe subgroup ($5.96 \pm 2.62^\circ$). Spinal rigidity increases in the elderly population due to deterioration of the muscles, ligaments, intervertebral discs, and vertebral bodies [24, 28, 29]. The mobility decline of the lumbar spine and spinal inclination make people more susceptible to falls due to the altered biomechanical stability of the spine [30]. Therefore, decreasing the range of spinal motion, loss of spinal lordosis, and weakening of the back muscle are suggested as critical factors for predicting falls [30].

Although thoracic and thoracolumbar hyperkyphosis increases the risk of future spine fracture in patients with previous fractures [24], the neutral posture for radiographic evaluation may be insufficient to describe the internal mechanical state of vertebral compression fractures. Previous studies ran a spinal simulation in vertical and neutral mechanical states, but most low-energy spinal injuries are caused in the lumbar hyperflexion posture [9, 10]. The thoracolumbar hyperflexion Cobb angle, an indicator of hyperflexion lumbar posture, may help assess the risk of future spinal fracture. Hyperflexion lumbar radiography provides an approach to evaluate this risk using TLHCobb information. Our study showed that the prevalence of fractures was related to the degree of TLHCobb. In postmenopausal women, the prevalence of fractures with relevant TLHCobbs of 14.85° to 20.05° or greater than 20.05° before injury was 2.8 or 4.8 times higher than that in fractures with TLHCobbs less than 14.85°, respectively. This increasing trend in the prevalence of fracture could explain the increased risk of adjacent or other vertebral fractures due to increased kyphosis produced by anterior-wedge-deformed vertebra (no evident fracture plane or remembered injury) [31]. Similarly, increased kyphosis caused by vertebral fractures could increase the risk of other vertebral fractures [32, 33]. Therefore, TLHCobbs can serve as radiographic references for vertebral compression fractures.

Postmenopausal women with TLHCobbs > 14.85° are advised to change postures via sacrospinal muscle exercises and the use of auxiliary extension braces during anti-osteoporosis treatments [34, 35]. For those with a TLHCobb > 20.05°, a walking stick or supporting frame is advisable to be part of the treatment. It is important to change posture in women with hyperkyphosis, regardless of vertebral fracture [36, 37]. Hyperkyphosis generally causes postmenopausal women to experience functional limitations and quality-of-life declines [36] and even increased mortality [28, 38, 39]

Due to the retrospective nature of the study and the relatively small sample size, our study only preliminarily established the association between vertebral compression fractures and TLHCobbs. In the next step, we will conduct a prospective study and increase the number of hyperflexion lumbar X-rays for postmenopausal women in our outpatient department and other medical centers. The new evidence may further clarify the association between TLHCobbs and future vertebral compression fractures.

Conclusions

Vertebral compression fractures are associated with TLHCobbs in menopausal women. The prevalence of vertebral fracture in osteoporotic women with TLHCobbs > 14.85° or 20.05° was 2.79 times or 4.83 times higher than in women with TLHCobbs < 14.85°, respectively. Therefore, a TLHCobb > 20.05° can be used as a high-risk marker of vertebral compression fractures and indicate the need for corrective treatments in postmenopausal women.

Declarations

Ethics approval and consent to participate: The experimental protocol was established, according to the ethical guidelines of the Helsinki Declaration and was approved by the Human Ethics Committee of

Chinese PLA General Hospital. Written informed consent was obtained from individual or guardian participants.

Consent for publication: Not applicable.

Availability of data and material: The datasets generated and/or analysed during the current study are not publicly available due to the confidentiality policy of military hospital but are available from the corresponding author on reasonable request.

Competing interests: ZhiRong Zheng, Tian Tian, WeiBo Liu, XiangYu Wang, Meng Gao, YongGang You, WenHao Hu and XueSong Zhang declare that they have no conflict of interest.

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Authors' contributions: ZhiRong Zheng, Tian Tian, WeiBo Liu, XiangYu Wang, Meng Gao and YongGang You analyzed and interpreted the patient data regarding the thoracolumbar fractures and the lumbar instability or spondylolisthesis. ZhiRong Zheng, WenHao Hu and XueSong Zhang were three major contributors in writing the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

A neutral spine posture is relatively static and persistent (A). A dynamic and transient hyperflexion posture (B) under compression shows the stress process of most low-energy vertebral fractures. The TLHCobb is the key indicator for this process.

Figure 2

DTLCobb is the difference between neutral spine posture in A and hyperflexion spine posture in B:

$$\text{DTLCobb} = \text{TLHCobb.p} - \text{TLCobb.p}$$

Figure 3

The region of interest (ROI) was defined as the largest ellipse in vertebral cancellous bone in the axial position. It has been found that taking the largest ellipse can make the value of the vertebral body BMD more stable and reduce the influence of local hyperplasia and sclerosis in the vertebral body on the BMD value.

Figure 4

Angles of 14.85° and 20.05° were determined using the ROC curve and Youden's index