Accuracy of spinal curvature assessed by a computer-assisted device and anthropometric indicators in discriminating vertebral fractures among individuals with back pain

Satoshi Mizukami[1), 2)], Yasuyo Abe[1)], Ritsu Tsujimoto[3)], Kazuhiko Arima[1)], Mitsuo Kanagae[1), 2)], Goji Chiba[4)], Kiyoshi Aoyagi[1)]

[1)]Department of Public Health, Nagasaki University Graduate School of Biomedical Sciences, 1-12-4 Sakamoto, Nagasaki 852-8523, Japan
[2)]Department of Rehabilitation, Nishi-Isahaya Hospital, 3015 Kaizu, Isahaya, Nagasaki 854-0063, Japan
[3)]Department of Orthopedic Surgery, Nagasaki University Graduate School of Biomedical Sciences, 1-7-1 Sakamoto, Nagasaki 852-8501, Japan
[4)]Department of Orthopedic Surgery, Nishi-Isahaya Hospital, 3015 Kaizu, Isahaya, Nagasaki 854-0063, Japan

Address all correspondence to: Yasuyo Abe, MD, PhD
Department of Public Health, Nagasaki University Graduate School of Biomedical Sciences
1-12-4 Sakamoto, Nagasaki 852-8523, Japan
Tel.: +81 95 8197067; Fax.: +81 95 8197069
E-mail: yasuyo-a@nagasaki-u.ac.jp

Abstract

Summary This study examined the accuracy of thoracic and lumbar kyphotic angles as well as anthropometric indicators for discriminating patients with vertebral fracture among Japanese women >50 years old with back pain. Along with region-specific kyphotic angles and anthropometric indicators, the combination of thoracic and lumbar kyphotic angles offered the highest accuracy.

Introduction Vertebral fractures have been associated with thoracic kyphosis. However, reports on lumbar kyphotic changes in association with vertebral fracture are scarce. This study investigated the accuracy of thoracic kyphotic angle (TKA) and lumbar kyphotic angle (LKA) measurements as well as anthropometric indicators (wall–occiput distance (WOD) and rib–pelvis distance (RPD)) in discriminating patients with vertebral fracture.

Methods Lateral radiographs of the spine were obtained in 70 postmenopausal Japanese women who visited an orthopedic clinic with low back pain (mean age, 76.2±9.0 years). Radiographic vertebral fracture was diagnosed using quantitative measurement according to Japanese criteria. Osteoarthritis (OA) was defined as Kellgren–Lawrence (KL) grade 3 or higher. TKA and LKA were measured using SpinalMouse®. WOD and RPD were also measured.

Results At least one vertebral fracture was present in 49 subjects (70 %). Women with vertebral fractures showed significant increases in LKA, TKA+LKA, and WOD and decreases in RPD. Logistic regression analysis showed significant association between TKA+LKA and vertebral fracture independent of the presence of OA. Receiver operating characteristic analysis revealed that TKA was useful for discriminating thoracic fractures (area under the curve (AUC), 0.730) and LKA was useful for lumbar fractures (AUC, 0.691). The combination of TKA+LKA offered the highest accuracy for detecting thoracic, lumbar, and any vertebral fractures, with AUCs of 0.779, 0.728, and 0.783, respectively. WOD and RPD showed low-to-moderate accuracies for thoracic, lumbar, and any vertebral fractures.

Conclusions Assessment of spinal kyphosis by SpinalMouse® as well as anthropometric indicators proved useful in discriminating subjects with vertebral fractures. These convenient and radiation-free methods could contribute to early diagnosis of vertebral fractures and subsequent appropriate treatment, thus preventing additional osteoporotic fractures.

Keywords

Lumbar kyphotic angle (LKA). Osteoporosis. Rib–pelvis distance (RPD). Thoracic kyphotic angle (TKA). Vertebral fracture . Wall–occiput distance (WOD)

Introduction

Vertebral fracture is the most frequent form of osteoporotic fracture, occurring in approximately 20 % of postmenopausal women [1–3]. Vertebral fracture is an important harbinger of future vertebral and non-vertebral fracture, independent of bone mineral density [4, 5], and is associated with back pain and both worsening quality of life [6, 7] and disability in activities of daily living [8]. However, two thirds of vertebral fractures do not come to clinical attention [9, 10] because symptoms are absent or missed (morphometric) [11, 12]. Identifying individuals at high risk of vertebral fractures and starting appropriate treatments are thus important for preventing additional osteoporotic fractures.

The gold standards for the diagnosis of vertebral fractures are anterior–posterior and lateral radiography, magnetic resonance imaging, or computed tomography. However, those procedures involve radiation exposure, are expensive, or are of limited availability. Establishment of alternative screening methods to detect vertebral fractures is therefore necessary.

Some anthropometric indicators have been used to screen for vertebral fractures. Wall–occiput distance (WOD) has been used to assess hyperkyphosis and has been shown to be associated with thoracic fracture [13] and vertebral fracture [14, 15]. WOD describes the distance between a wall and the occiput when the patient stands straight with heels and back against the wall. Because the decreased height of a fractured lumbar vertebra reduces the distance between the inferior margin of the ribs and the anterior superior iliac crest of the pelvis [16, 17], rib–pelvis distance (RPD, measured in fingerbreadths on physical examination) has also been used to detect lumbar fracture [18].

Vertebral fractures have been reported to cause thoracic hyperkyphosis [13, 19–23]. Moreover, thoracic kyphosis itself has been reported as a risk factor of future fracture, regardless of the presence of vertebral fracture [22, 24]. However, reports assessing the association between degree of lumbar lordosis and vertebral fracture are scarce [21, 25]. SpinalMouse®, a computerized radiation-free device for measuring surface curvature, has recently been applied to directly and easily measure thoracic kyphotic angle (TKA) and lumbar kyphotic angle (LKA) [26–28].

The purpose of this study was to investigate the accuracies of TKA and LKA measurements by SpinalMouse® as well as the anthropometric indicators WOD and RPD in discriminating patients with vertebral fracture.

Subjects and methods

Subjects

This study was a cross-sectional study, which was run in a clinical setting. Subjects were 70 postmenopausal Japanese women (mean age, 76.2 years; range, 51–90 years) who visited an orthopedic outpatient clinic with low back pain. All subjects provided written informed consent prior to participation in the study. The study protocols were approved by the ethics committee at Nagasaki University Graduate School of Biomedical Sciences.

Spine radiographic assessment (vertebral fractures and osteoarthritis)

Lateral spine radiographs were obtained with the subject in a standing position. All radiographs were obtained using a tubeto- film distance of 100 cm, with the tube positioned approximately over T8 for thoracic films and L2 for lumbar films.

Vertebral fractures

Radiographs were evaluated morphometrically by a single reader (SM). Anterior (A), central (C), and posterior heights (P) of each thoracic (T4–T12), and lumbar (L1–L5) vertebral body were measured on lateral films with the aid of digital calipers. Points indicating the border of the vertebral centrum were chosen based on the procedure described by Gallagher et al. [29] and Spencer et al. [30]. Vertebral fractures were defined using quantitative measurements according to Japanese criteria [31]. Presence of a vertebral fracture was confirmed based on the following: (1) a reduction in vertebral height of >20 % (A, C, and P) as compared with the height of the adjacent vertebrae was observed; (2) C/A or C/P was <0.8; or (3) A/P was <0.75.

Vertebral osteoarthritis

Radiographs were scored by a single reader (RT) for osteoarthritis of the thoracic spine in T4–T12 or lumbar spine in L1– L4 using the Kellgren–Lawrence (KL) grade as follows: KL0, normal; KL1, slight osteophytes; KL2, definite osteophytes; KL3, disk space narrowing with large osteophytes; and KL4, bone sclerosis, disk space narrowing, and large osteophytes [32]. In the present study, we defined the spine with disk space narrowing with and without osteophytes as KL3 [33]. KL grade was determined at intervertebral spaces, and the highest scores among thoracic or lumbar intervertebral spaces were then identified as the KL grade for that individual. Osteoarthritis was defined as KL grade 3 or higher in this study.

TKA and LKA measurements

TKA (T1–T12) and LKA (T12–S1) were measured with a device for computerized measurement of surface curvature (SpinalMouse®; Iding, Volkerswill, Switzerland) in the upright position. Details regarding this device have been published previously [26]. In brief, by sliding this device along the spinal curvature, the superficial back length from C7 to S3 and the local angle of each point of this length relative to the plumb line along with TKA and LKA are calculated and displayed on the computer monitor [26]. A positive value means the spine is kyphotic, while a negative value means the spine is lordotic. Intra-class coefficients (ICCs) for curvature measurement with SpinalMouse® have been reported as 0.92–0.95 [26]. Another report described intra-rater ICCs ranging from 0.82 to 0.83 and inter-rater ICCs ranging from 0.81 to 0.86 [28].

Anthropometric measurements

Height and weight were measured. Body mass index (BMI) was calculated as weight (kg)/height (m)2. WOD describes the difference between a wall and the occiput when the patient stands straight with the heels and back against the wall and the head positioned such that an imaginary line from the lateral corner of the eye to the superior junction of the auricle is parallel to the floor [34]. The horizontal distance between the wall and back of the head was measured in increments of 0.5 cm. RPD was measured by a single examiner (SM). The hands of the examiner were inserted into the space between the inferior margin of the ribs and the superior surface of the pelvis in the midaxillary line [18]. RPD was measured in units of 0.5 fingerbreadth.

Statistical analysis

The Kruskal–Wallis test was used to determine the significance of differences between groups. The associations of TKA and LKA measurements, WOD, and RPD with vertebral fractures were assessed using logistic regression analysis in crude models and models adjusted for age, BMI, and presence of osteoarthritis in the respective region. The odds ratio (OR) and its 95 % confidence interval (95% CI) were calculated. Receiver operating characteristic (ROC) curves were generated by calculating the sensitivity and specificity of TKA and LKA measurements, WOD, and RPD in discriminating patients with vertebral fracture (thoracic, lumbar, and any fractures), and areas under the curve (AUCs) with 95 % confidence intervals (CI) were calculated. Negative and positive predictive values were also calculated for selected cutoff points. All statistical analyses were performed using SAS version 9.2 software (SAS Institute, Cary, NC).

Results

Table 1 summarizes the basic characteristics of study subjects. Mean (standard deviation) age and BMI were 76.2 (9.0)years and 23.3 (3.2)kg/m2, respectively. Of the 70 subjects, 49 (70 %) showed the presence of at least one vertebral fracture. Prevalence of vertebral osteoarthritis (KL ≥3) was 48 (68.6 %) in this population.

SpinalMouse® parameters (TKA, LKA, TKA+LKA) and anthropometric indicators (WOD, RPD) were compared between women with no, one, and two or more vertebral fractures (Table 2). Presence of thoracic fracture was significantly associated with increased TKA, TKA+LKA, WOD, and decreased RPD. Presence of lumbar fracture was significantly associated with increased LKA and TKA+LKA and decreased RPD. Presence of vertebral fracture (thoracic and/or lumbar fracture) was significantly associated with increased LKA, TKA+LKA, and WOD and decreased RPD, while vertebral fracture was marginally associated with increased TKA.

Association of SpinalMouse® parameters (TKA, LKA, TKA+LKA) and anthropometric indicators (WOD, RPD) with vertebral fractures was assessed using logistic regression analysis, in crude models and models adjusted for age, BMI, and presence of osteoarthritis (KL ≥3) (Table 3). In the adjusted models, increased TKA+LKAwas significantly associated with increased risk of thoracic, lumbar, and vertebral fractures: respective odds ratio (OR) for 10° increase in TKA+LKA was 1.66, 1.62, and 2.13. Increased TKAwas significantly associated with higher risk of thoracic fracture (OR, 1.85), while TKAwas not associated with lumbar fracture and vertebral fracture. Increased LKA was significantly associated with lumbar fracture (OR, 2.20), while LKA was not associated with thoracic and vertebral fracture. WOD was not significantly associated with thoracic, lumbar, and vertebral fracture. Decreased RPD was associated with higher risk of lumbar fracture. RPD was not associated with thoracic fracture, while decreased RPD was marginally associated with vertebral fracture.

ROC analysis was performed to assess the accuracy of TKA and LKA measurements, WOD, and RPD in discriminating patients with vertebral fractures (thoracic, lumbar, and any vertebral fractures). As shown in Table 4, TKA showed a moderate AUC of 0.73 for thoracic fracture, but did not prove useful for discriminating lumbar fracture. LKA showed a moderate AUC of 0.69 for lumbar fracture, but did not prove useful for discriminating thoracic fracture. WOD and RPD showed low-to-moderate AUCs for both thoracic and lumbar fractures. As for vertebral fractures, all measurements showed low-to-moderate accuracy. TKA+LKA showed the highest AUCs for thoracic, lumbar, and any vertebral fractures.

Sensitivity, specificity, positive predictive value, and negative predictive value for selected cutoff points are shown in Table 5. When 30° was used as a cutoff value, TKA+LKA showed 78 % sensitivity and 62 % specificity for vertebral fracture, good positive predictive value (0.83), and a somewhat lower negative predictive value (0.54). At the same cutoff value, TKA+LKA showed good sensitivity and somewhat lower specificity for thoracic and lumbar fractures. At cutoff values of 0 cm for WOD and 2 fingerbreadths for RPD, WOD and RPD showed moderate sensitivities and specificities for thoracic, lumbar, and any vertebral fractures.

Discussion

Our study showed that assessment of thoracic and lumbar kyphosis by SpinalMouse® offered moderate accuracy in discriminating women with vertebral fracture. Although region-specific kyphotic angle (i.e., TKA for thoracic fracture) was shown to be useful, the combination of TKA+LKA appeared to be the most useful in discriminating subjects with vertebral fracture. Anthropometric indicators (WOD and RPD) also provided low-to-moderate accuracy in discriminating women with vertebral fracture. To the best of our knowledge, this is the first study to show the accuracy of measuring TKA and LKA by SpinalMouse® for raising suspicion of vertebral fractures.

Vertebral fractures have been reported as one of the major causative factors for thoracic kyphosis [13, 19–23]. Increased thoracic kyphosis has been observed in women and men with vertebral fracture compared to those without vertebral fractures [23]. In addition, subjects with thoracic fracture have been reported to show significantly increased thoracic kyphosis [13, 19, 22]. De Smet et al. [20] showed that the number of wedge thoracic fractures correlated with the degree of thoracic kyphosis.

Few studies have examined the relationship between lumbar fracture and lumbar kyphosis. Our data showed a significant association between lumbar fracture and increased lumbar kyphosis. Previous studies have reported decreases in lumbar lordosis with advancing age [27, 35, 36]. Part of this lumbar kyphotic change would be caused by vertebral fractures. Lyles et al. [37] reported decreased lumbar lordosis among individuals with vertebral fracture. Moreover, the degree of lumbar kyphosis as assessed by SpinalMouse® has been reported to show significant positive correlations with the number of vertebral fractures [27]. Ishikawa et al. [38] reported that the degree of lumbar kyphosis evaluated by SpinalMouse® was associated with postural instability in osteoporosis patients. Increasing lumbar kyphosis related to lumbar fracture would be an important cause of postural imbalance, which might lead to future falls and fractures.

WOD and RPD have been reported to be useful in discriminating subjects with vertebral fracture [13, 14, 18]. Siminoski et al. [13] reported that WOD offered moderate accuracy in discriminating subjects with thoracic fracture among 280 female Caucasians, with an AUC of 0.76, 71 % sensitivity, and 76 % specificity at a threshold of WOD >0. Siminoski et al. [18] also reported the accuracy of RPD in discriminating subjects with lumbar fracture, with an AUC of 0.72 and 76 % sensitivity at a threshold of ≤2 fingerbreadths. Our results showed moderate accuracy of WOD for detecting thoracic fracture and RPD for detecting lumbar fracture, consistent with previous findings.

In our study, both WOD and RPD showed moderate accuracy in discriminating vertebral fractures, with an AUC of about 0.7, although no significant association was found in the adjusted logistic regression models. Abe et al. [14] assessed the discriminative ability of WOD and RPD for vertebral fractures and showed that WOD, but not RPD, was associated with the presence of vertebral fracture. Vosse et al. [15] showed that among patients with ankylosing spondylitis, subjects with WOD >0 had a greater number of vertebral fractures. Tobias et al. [39] reported that an RPD of 1 fingerbreadth was associated with vertebral fracture. On the other hand, Balzini et al. [40] reported that WOD was not significantly associated with vertebral fracture. Although further study is necessary to clarify associations between WOD, RPD, and vertebral fractures, these anthropometric indicatorsmay represent good alternative methods of screening for vertebral fracture.

In this study, increased region-specific kyphotic angle (i.e., TKA for thoracic fracture) was significantly associated with higher prevalence of vertebral fracture after adjusting for age, BMI, and presence of osteoarthritis (OA) and shown to be useful in discriminating subjects with vertebral fracture. Kraus et al. [25] recently assessed thoracic kyphosis (TK), lumbar lordosis (LL), and trunk inclination using radiation-free spinometry and showed the low-to-moderate accuracy of TK increase for discriminating subjects with thoracic fracture and of LL decrease for discriminating subjects with lumbar fracture. These findings might show that thoracic fractures cause thoracic kyphosis and that lumbar fractures cause lumbar kyphosis. On the other hand, in our study, TKA was not significantly associated with lumbar fracture. In addition, LKA was not associated with thoracic fracture. Ensrud et al. [21] showed that thoracic kyphosis was not correlated with the number of lumbar fractures, consistent with our findings. However, Krause et al. [25] reported that thoracic fractures influence lumbar kyphosis and that lumbar fractures influence thoracic kyphosis. Further study is necessary to elucidate these associations.

TKA+LKA, the combination of thoracic and lumbar kyphosis as measured by SpinalMouse®, was the only parameter that was significantly associated with thoracic, lumbar, and vertebral fracture after adjusting for age, BMI, and presence of OA and offered the highest accuracy of all measurements for each fracture in this study. Kraus et al. [25] reported that among other variables (TK, LL, and trunk inclination), TK+LL provided the highest discriminating power for both thoracic fracture and lumbar fracture (AUC, 0.752–0.771). Sensitivity and specificity of TK (cutoff value, 50°) for thoracic fracture and LL (cutoff value, 40°) for lumbar fracture were 88–100 and 23– 25 % and 78–92 and 24–27 %, respectively [25]. In our study, when 30° was used as a cutoff value, TKA+LKA showed comparable sensitivity and better specificity for vertebral fracture, and it showed good positive predictive value (0.83) among women with back pain. This cutoff would be suitable for screening among Japanese women with back pain to raise suspicion of vertebral fractures. Since thoracic kyphosis and lumbar kyphosis are reportedly increased in vertebral fracture subjects [37], assessing the degree of thoracic and lumbar kyphosis as a whole, rather than assessing thoracic or lumbar kyphosis separately, might be useful in screening for undiagnosed vertebral fractures among individuals with back pain.

Several limitations must be considered when interpreting the present results. First, the number of subjects was relatively small, making it difficult to analyze the associations of spinal curvature measurements and anthropometric indicators with different numbers or types of vertebral fracture. Of the 49 individuals with vertebral fractures, 43 had at least one wedge fracture (data not shown). Therefore, the findings of the study might possibly be due to the wedge fractures. Larger study would be needed to evaluate effects of different numbers or types of vertebral fractures on spinal curvature. Second, we used the classification of the Japanese Society for Bone and Mineral Research for defining vertebral fracture, but some studies have used different definitions [13, 14, 18]. Careful interpretation is needed to compare these studies directly. Third, we did not obtain information about other factors that could have influenced hyperkyphosis, such as back muscle weakness [41, 42]. Fourth, our subjects were orthopedic outpatients with low back pain, which may have contributed to selection bias. Fifth, because this study only included women, the present findings may not be generalizable to men.

In conclusion, assessment of thoracic and lumbar kyphosis by SpinalMouse® as well as anthropometric indicators (WOD and RPD) proved useful in discriminating subjects with vertebral fractures. These convenient, radiation-free methods would contribute to raise suspicion of vertebral fractures and help clinician to indicate proper diagnostics to detect vertebral fractures, subsequent appropriate treatment, thus help to prevent additional osteoporotic fractures.

Acknowledgments The authors would like to thank the subjects andstaff at the participating hospital for allowing us to conduct this study.

Conflicts of interest None.

References

1. Eastell R, Cedel SL, Wahner HW, Riggs BL, Melton LJ 3rd (1991) Classification of vertebral fractures. J Bone Miner Res 6:207–215

2. Clark P, Cons-Molina F, Deleze M et al (2009) The prevalence of radiographic vertebral fractures in Latin American countries: the Latin American Vertebral Osteoporosis Study (LAVOS). Osteoporos Int 20:275–282

3. Sadat-Ali M, Gullenpet AH, Al-Mulhim F, Al Turki H, Al- Shammary H, Al-Elq A, Al-Othman A (2009) Osteoporosis-related vertebral fractures in postmenopausal women: prevalence in a Saudi Arabian sample. East Mediterr Health J 15:1420–1425

4. Lunt M, O'Neill TW, Felsenberg D, Reeve J, Kanis JA, Cooper C, Silman AJ (2003) Characteristics of a prevalent vertebral deformity predict subsequent vertebral fracture: results from the European Prospective Osteoporosis Study (EPOS). Bone 33:505–513

5. Ross PD, Davis JW, Epstein RS, Wasnich RD (1991) Pre-existing fractures and bone mass predict vertebral fracture incidence in women. Ann Intern Med 114:919–923

6. Kitahara H, Ye Z, Aoyagi K et al (2012) Associations of vertebral deformities and osteoarthritis with back pain among Japanese women: the Hizen-Oshima study. Osteoporos Int 24: 907–915

7. Rikli R, Jones C (1999) Development and validation of a functional fitness test for community-residing older adults. J Aging Phys Act 7: 129–161

8. Antonelli-Incalzi R, Pedone C, Cesari M, Di Iorio A, Bandinelli S, Ferrucci L (2007) Relationship between the occiput-wall distance and physical performance in the elderly: a cross sectional study. Aging Clin Exp Res 19:207–212

9. O'Neill TW, Felsenberg D, Varlow J, Cooper C, Kanis JA, Silman AJ (1996) The prevalence of vertebral deformity in european men and women: the European Vertebral Osteoporosis Study. J Bone Miner Res 11:1010–1018

10. Spector TD, McCloskey EV, Doyle DV, Kanis JA (1993) Prevalence of vertebral fracture in women and the relationship with bone density and symptoms: the Chingford Study. J Bone Miner Res 8:817–822

11. Fechtenbaum J, Cropet C, Kolta S, Verdoncq B, Orcel P, Roux C (2005) Reporting of vertebral fractures on spine X-rays. Osteoporos Int 16:1823–1826

12. McKiernan FE (2009) The broadening spectrum of osteoporotic vertebral fracture. Skeletal Radiol 38:303–308

13. Siminoski K,Warshawski RS, Jen H, LeeKC (2011) The accuracy of clinical kyphosis examination for detection of thoracic vertebral fractures: comparison of direct and indirect kyphosis measures. J Musculoskelet Neuronal Interact 11:249–256

14. Abe K, Tamaki J, Kadowaki E, Sato Y, Morita A, Komatsu M, Takeuchi S, Kajita E, Iki M (2008) Use of anthropometric indicators in screening for undiagnosed vertebral fractures: a cross-sectional analysis of the Fukui Osteoporosis Cohort (FOC) study. BMC Musculoskelet Disord 9:157

15. Vosse D, van der Heijde D, Landewe R, Geusens P, Mielants H, Dougados M, van der Linden S (2006) Determinants of hyperkyphosis in patients with ankylosing spondylitis. Ann Rheum Dis 65:770–774

16. Culham EG, Jimenez HA, King CE (1994) Thoracic kyphosis, rib mobility, and lung volumes in normal women and women with osteoporosis. Spine 19:1250–1255

17. Leidig-Bruckner G, Minne HW, Schlaich C, Wagner G, Scheidt- Nave C, Bruckner T, Gebest HJ, Ziegler R (1997) Clinical grading of spinal osteoporosis: quality of life components and spinal deformity in women with chronic low back pain and women with vertebral osteoporosis. J Bone Mineral Res: Off J Am Soc Bone Mineral Res 12:663–675

18. Siminoski K, Warshawski RS, Jen H, Lee KC (2003) Accuracy of physical examination using the rib-pelvis distance for detection of lumbar vertebral fractures. Am J Med 115:233–236

19. Cortet B, Roches E, Logier R, Houvenagel E, Gaydier-Souquieres G, Puisieux F, Delcambre B (2002) Evaluation of spinal curvatures after a recent osteoporotic vertebral fracture. Joint Bone Spine 69:201–208

20. De Smet AA, Robinson RG, Johnson BE, Lukert BP (1988) Spinal compression fractures in osteoporotic women: patterns and relationship to hyperkyphosis. Radiology 166:497–500

21. Ensrud KE, Black DM, Harris F, Ettinger B, Cummings SR (1997) Correlates of kyphosis in older women. The Fracture Intervention Trial Research Group. J Am Geriatr Soc 45:682–687

22. Roux C, Fechtenbaum J, Kolta S, Said-Nahal R, Briot K, Benhamou CL (2010) Prospective assessment of thoracic kyphosis in postmenopausal women with osteoporosis. J BoneMineral Res:Off JAmSoc Bone Mineral Res 25:362–368

23. Schneider DL, von Muhlen D, Barrett-Connor E, Sartoris DJ (2004) Kyphosis does not equal vertebral fractures: the Rancho Bernardo study. J Rheumatol 31:747–752

24. Huang MH, Barrett-Connor E, Greendale GA, Kado DM (2006) Hyperkyphotic posture and risk of future osteoporotic fractures: the Rancho Bernardo study. J Bone Mineral Res: Off J Am Soc Bone Mineral Res 21:419–423

25. KrauseM, Breer S,Mohrmann B, Vettorazzi E, Marshall RP, Amling M, Barvencik F (2013) Influence of non-traumatic thoracic and lumbar vertebral fractures on sagittal spine alignment assessed by radiation-free spinometry. Osteoporos Int: J Established Result Cooperation Between Eur Found Osteoporos Nat Osteoporos Foun USA 24:1859–1868

26. Post RB, Leferink VJ (2004) Spinalmobility: sagittal range ofmotion measured with the SpinalMouse, a new non-invasive device. Arch Orthop Trauma Surg 124:187–192

27. Miyakoshi N, Hongo M, Maekawa S, Ishikawa Y, Shimada Y, Okada K, Itoi E (2005) Factors related to spinal mobility in patients with postmenopausal osteoporosis. Osteoporos Int 16: 1871–1874

28. Mannion AF, Knecht K, Balaban G, Dvorak J, Grob D (2004) A new skin-surface device for measuring the curvature and global and segmental ranges of motion of the spine: reliability of measurements and comparison with data reviewed from the literature. Eur Spine J: Off Publ Eur Spine Soc, Eur Spinal Deformity Soc Eur Sect Cervical Spine Res Soc 13:122–136

29. Gallagher JC, Hedlund LR, Stoner S, Meeger C (1988) Vertebral morphometry: normative data. Bone Miner 4:189–196

30. Spencer N, Steiger P, Cummings S, Genant H (1990) Placement of points for digitizing spine films. J Bone Miner Res 5:s247

31. Mori S, Soen S, Hagino H et al (2013) Justification criteria for vertebral fractures: year 2012

revision. J Bone Miner Metab 31: 258–261

32. Kellgren JH, Lawrence JS (1957) Radiological assessment of osteoarthrosis. Ann Rheum Dis 16:494–502

33. Yoshimura N, Muraki S, Oka H, Mabuchi A, Kinoshita H, Yosihda M, Kawaguchi H, Nakamura K, Akune T (2009) Epidemiology of lumbar osteoporosis and osteoarthritis and their causal relationship is osteoarthritis a predictor for osteoporosis or vice versa?: the Miyama study. Osteoporos Int 20:999–1008

34. Green AD, Colon-Emeric CS, Bastian L, Drake MT, Lyles KW (2004) Does this woman have osteoporosis? JAMA 292: 2890–2900

35. Gelb DE, Lenke LG, Bridwell KH, Blanke K, McEnery KW (1995) An analysis of sagittal spinal alignment in 100 asymptomatic middle and older aged volunteers. Spine (Phila Pa 1976) 20:1351–1358

36. Milne JS, Lauder IJ (1974) Age effects in kyphosis and lordosis in adults. Ann Hum Biol 1:327–337

37. Lyles KW, Gold DT, Shipp KM, Pieper CF, Martinez S, Mulhausen PL (1993) Association of osteoporotic vertebral compression fractures with impaired functional status. Am J Med 94:595–601

38. Ishikawa Y, Miyakoshi N, Kasukawa Y, Hongo M, Shimada Y (2009) Spinal curvature and postural balance in patients with osteoporosis. Osteoporos Int 20:2049–2053

39. Tobias JH, Hutchinson AP, Hunt LP, McCloskey EV, Stone MD, Martin JC, Thompson PW, Palferman TG, Bhalla AK (2007) Use of clinical risk factors to identify postmenopausal women with vertebral fractures. Osteoporos Int: J Established Result Cooperation Between Eur Found Osteoporos Nat Osteoporos Found USA 18:35–43

40. Balzini L, Vannucchi L, Benvenuti F, Benucci M, Monni M, Cappozzo A, Stanhope SJ (2003) Clinical characteristics of flexed posture in elderly women. J Am Geriatr Soc 51:1419–1426

41. Katzman WB, Wanek L, Shepherd JA, Sellmeyer DE (2010) Agerelated hyperkyphosis: its causes, consequences, and management. J Orthop Sports Phys Ther 40:352–360

42. Sinaki M, Itoi E, Rogers JW, Bergstralh EJ, Wahner HW (1996) Correlation of back extensor

strength with thoracic kyphosis and lumbar lordosis in estrogen-deficient women. Am J Phys Med Rehabil/Assoc Acad Physiatrists 75:370–374

Table 1. Characteristics of study subjects (N=70)

Variables	
	mean (SD)
Age	76.2 (9.0)
Height	147.3 (7.1)
Weight	50.8 (8.7)
Body mass index	23.3 (3.2)
	Number (%)
Vertebral fracture	
0	21 (30.0)
1	20 (28.6)
2+	29 (41.4)
Thoracic fracture	
0	31 (44.3)
1	20 (28.6)
2+	19 (27.1)
Lumbar fracture	
0	36 (51.4)
1	27 (38.6)
2+	7 (10.0)
Vertebral osteoarthritis	
KL>=2	65 (92.9)
KL>=3	48 (68.6)
Thoracic osteoarthritis	
KL>=2	52 (74.3)
KL>=3	19 (27.1)
Lumbar osteoarthritis	
KL>=2	61 (87.1)
KL>=3	43 (61.4)

Table 2. Comparison of SpinalMouse® parameters and anthropometric indicators between subjects with no, one, and two or more vertebral fractures (N=70)

	Thoracic fracture			p-value
	0 (N=31)	1 (N=20)	2+ (N=19)	
TKA+LKA (°)[a]	26.0 (19.0, 40.0)	41 (35.0, 53.5)	51.0 (32.0, 56.0)	p<0.001
TKA (°)[a]	40.0 (31.0, 48.0)	51.5 (41.5, 58.5)	47.0 (36.0, 64.0)	p=0.004
LKA (°) [a]	-13.0 (-17.0, -3.0)	-12.5 (-14.5, -3.0)	-8.0 (-15.0, 3.0)	p=0.22
WOD (cm) [a]	0.0 (0.0, 1.5)	1.75 (0.0, 3.0)	4.0 (1.5, 5.5)	p=0.003
RPD (fingerbreadths) [a]	2.5 (2.0, 3.0)	2.0 (1.5, 3.0)	2.0 (1.0, 2.5)	p=0.049
	Lumbar fracture			
	0 (N-36)	1 (N=27)	2+ (N=7)	
TKA+LKA (°)	34.5 (18.5, 40.5)	48 (31, 56)	37 (25, 55)	p=0.004
TKA (°)	44.5 (35, 52)	44 (38, 57)	41 (30, 61)	p=0.75
LKA (°)	-13.5 (-17, -7)	-3 (-15, 9)	-9 (-15, -6)	p=0.019
WOD (cm)	0.0 (0.0, 2.0)	2.0 (0.0, 5.5)	1.5 (0.0, 4.0)	p=0.10
RPD (fingerbreadths)	2.5 (2.0, 3.0)	2.0 (1.5, 2.5)	1.5 (1.0, 2.0)	p=0.003
	Vertebral fracture			
	0 (N=21)	1 (N=20)	2+ (N=29)	
TKA+LKA (°)	23 (16, 35)	36.5 (26, 44)	51 (32, 56)	p<0.001
TKA (°)	42 (31, 48)	45.5 (35.5, 51.5)	47 (40, 61)	p=0.083
LKA (°)	-14 (-17, -7)	-10 (-16.5, 1.5)	-8 (-14, 3)	p=0.031
WOD (cm)	0.0 (0.0, 1.0)	1.0 (0.0, 2.0)	2.5 (0.0, 5.5)	p=0.006
RPD (fingerbreadths)	2.5 (2.0, 3.0)	2.0 (2.0, 3.0)	2.0 (1.5, 2.5)	p=0.007

TKA, thoracic kyphotic angle; LKA, lumbar kyphotic angle; WOD, wall-occiput distance; RPD, rib-pelvis distance.

[a]Median (interquartile range)

Table 3. Associations of SpinalMouse® parameters and anthropometric indicators with vertebral fractures

independent variables	units	thoracic fracture crude	thoracic fracture adjusted*
		OR (95%CI)	OR (95%CI)
TKA+LKA (°)	+10	2.03 (1.37–3.01)	1.66 (1.10–2.52)
TKA (°)	+10	1.99 (1.27–3.12)	1.85 (1.13–3.03)
LKA (°)	+10	1.36 (0.94–1.96)	1.15 (0.76–1.75)
WOD (cm)	+5	2.31 (0.94–5.68)	1.60 (0.73–3.52)
RPD (fingerbreadths)	-0.5	1.43 (1.01–2.02)	1.15 (0.78–1.71)
		lumbar fracture	
TKA+LKA (°)	+10	1.72 (1.13–2.42)	1.62 (1.14–2.31)
TKA (°)	+10	1.12 (0.77–1.62)	1.02 (0.69–1.53)
LKA (°)	+10	2.12 (1.27–3.55)	2.20 (1.25–3.90)
WOD (cm)	+5	1.61 (0.90–2.89)	1.36 (0.79–2.35)
RPD (fingerbreadths)	-0.5	1.63 (1.14–2.35)	1.50 (1.01–2.23)
		vertebral fracture	
TKA+LKA (°)	+10	2.15 (1.37–3.38)	2.13 (1.27–3.59)
TKA (°)	+10	1.45 (0.95–2.22)	1.48 (0.91–2.42)
LKA (°)	+10	2.13 (1.16–3.92)	1.89 (0.98–3.66)
WOD (cm)	+5	6.26 (1.16–33.78)	3.37 (0.53–21.46)
RPD (fingerbreadths)	-0.5	1.70 (1.10–2.63)	1.47 (0.91–2.37)

TKA, thoracic kyphotic angle; LKA, lumbar kyphotic angle; WOD, wall-occiput distance; RPD, rib-pelvis distance.

* adjusted for age, body mass index and presence of osteoarthritis (KL>=3) in the respective region

Table 4. AUC with regard to vertebral fracture.

variables	Thoracic fracture	Lumbar fracture	Vertebral fracture
	AUC (95% CI)	AUC (95% CI)	AUC (95% CI)
TKA+LKA	0.779 (0.670−0.889)	0.728 (0.610−0.847)	0.783 (0.676−0.890)
TKA	0.730 (0.614−0.847)	0.537 (0.399−0.675)	0.631 (0.498−0.764)
LKA	0.614 (0.479−0.750)	0.691 (0.565−0.817)	0.689 (0.556−0.822)
WOD	0.698 (0.581−0.815)	0.641 (0.516−0.766)	0.700 (0.584−0.816)
RPD	0.635 (0.508−0.763)	0.713 (0.592−0.834)	0.696 (0.565−0.826)

TKA: thoracic kyphotic angle, LKA: lumbar kyphotic angle, WOD: wall-occiput distance, RPD: rib-pelvis distance

Table 5. Validity results for selected cut-off values with regard to vertebral fractures.

Cut-off value	Thoracic fracture	Lumbar fracture	Vertebral fracture
TKA+LKA (°)	sensitivity (%) / specificity (%) / positive predictive value / negative predictive value		
≥ 25	85 / 45 / 0.66 / 0.70	85 / 42 / 0.58 / 0.75	82 / 52 / 0.80 / 0.55
≥ 30	82 / 55 / 0.70 / 0.71	79 / 47 / 0.59 / 0.71	78 / 62 / 0.83 / 0.54
≥ 35	77 / 65 / 0.73 / 0.69	68 / 50 / 0.56 / 0.62	69 / 67 / 0.83 / 0.48
TKA (°)	sensitivity (%) / specificity (%) / positive predictive value / negative predictive value		
≥ 35	87 / 32 / 0.62 / 0.67	82 / 25 / 0.51 / 0.60	82 / 29 / 0.73 / 0.40
≥ 40	77 / 48 / 0.65 / 0.63	68 / 36 / 0.50 / 0.54	67 / 38 / 0.72 / 0.33
≥ 45	62 / 68 / 0.71 / 0.58	47 / 50 / 0.47 / 0.50	53 / 62 / 0.76 / 0.36
LKA (°)	sensitivity (%) / specificity (%) / positive predictive value / negative predictive value		
≥ -20	97 / 13 / 0.58 / 0.80	100 / 14 / 0.52 / 1.00	98 / 19 / 0.74 / 0.80
≥ -15	79 / 42 / 0.63 / 0.62	79 / 39 / 0.55 / 0.67	78 / 48 / 0.78 / 0.48
≥ -10	51 / 52 / 0.57 / 0.46	62 / 61 / 0.60/ 0.63	55 / 62 / 0.77 / 0.37
WOD (cm)	sensitivity (%) / specificity (%) / positive predictive value / negative predictive value		
> 0	67 / 61 / 0.68 / 0.59	65 / 56 / 0.58 / 0.63	63 / 67 / 0.82 / 0.44
RPD (fingerbreadths)	sensitivity (%) / specificity (%) / positive predictive value / negative predictive value		
≤2	64 / 58 / 0.66 / 0.56	74 / 64 / 0.66 / 0.72	65 / 71 / 0.84 / 0.47

TKA: thoracic kyphotic angle, LKA: lumbar kyphotic angle, WOD: wall-occiput distance, RPD: rib-pelvis distance