ORIGINAL ARTICLE

Biplanar Measurement of Thoracolumbar Curvature in Older Adults Using an Electromagnetic Tracking Device

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ABSTRACT. Singh DK, Bailey M, Lee R. Biplanar measurement of thoracolumbar curvature in older adults using an electromagnetic tracking device. Arch Phys Med Rehabil 2010; 91:137-42.

Objectives: To develop a new biplanar method of thoracolumbar curvature measurement by using an electromagnetic tracking device and to study the effects of aging on the thoracolumbar curvature.

Design: Cross-sectional study.

Setting: Human movement laboratory.

Participants: Healthy (N=52, 26 younger and 26 older) volunteers.

Interventions: Not applicable.

Main Outcome Measures: An electromagnetic tracking device was used to trace the thoracolumbar curvature by recording the positions of the spinous processes of the spine. The coordinates of the curvature were fitted with polynomial equations, and the magnitudes of thoracic kyphosis, lumbar lordosis, and lateral thoracic and lumbar curves were determined.

Results: The present technique was shown to be highly reliable in measuring thoracolumbar curvature with an intraclass correlation coefficient of more than .90. The mean thoracic kyphosis ($-46.95° \pm 11.41°$) in the older adults was significantly larger than that in the younger adults ($-38.82° \pm 9.86°$) ($P<.01$). However, there were no significant differences in lumbar lordosis and lateral curvatures between the 2 subject groups.

Conclusions: The present study provided evidence of an increase in thoracic kyphosis in older adults. The method of measurement presented in this study was found to provide reliable biplanar data that will be useful in a clinical setting.

Key Words: Aging; Rehabilitation.

THORACOLUMBAR CURVATURE is commonly altered in older adults, but what is considered as "normal" is not clear. "Normal" thoracolumbar curvature is necessary to maintain proper balance between muscle forces and external loads on the trunk.[1] Alteration in thoracolumbar curvature will alter the length-tension relationship of the spine muscles and their moment arms and, consequently, the ability of the muscles to generate force.[2,3]

Thoracic kyphosis has been reported to increase with age,[4-10] whereas observations about the lumbar lordosis have been inconsistent. Some studies reported a decrease in lordosis,[5-9] whereas others observed an increase[10] or no change in curvature.[11,12] In a study by Takahashi et al,[13] 11.9% of the participants were found to have decreased lumbar curvature, and 4.7% exhibited increased lordosis.

There are wide variations in the angles of the thoracolumbar curvatures of the normal spines.[4-10] This reflects the variations in the anthropometric characteristics of the trunk and is also attributable to the different measurement methodologies used and the different definitions of curvatures in previous work. Boyle et al[14] reported the mean ± SD thoracic kyphosis (first thoracic to twelfth thoracic) to be $25.9° \pm 3.8°$ for the younger age group, $42.2° \pm 2.4°$ for the middle age group, and $52.6° \pm 5.1°$ for the older age group. These measurements were obtained from postmortem spine x-rays[14] and might not represent the curvatures of the living spine in the upright posture.

Thoracolumbar curvature has been measured by using various techniques, including x-ray,[4,9,15-17] flexicurves,[17] kyphometers,[17] and a skin surface device called the "spinal mouse."[18,19] The radiographic method in measuring thoracolumbar curvature has a risk of radiation and should not be used as a routine clinical assessment tool. Although the "spinal mouse" technique is noninvasive and reliable,[18] the spine curvature can only be obtained in the sagittal plane, and the derivation of the thoracolumbar curvature angle using this method has not been reported in the literature. One major attraction of an electromagnetic tracking device is its ability to provide biplanar curvature data apart from being noninvasive and radiation free. This instrument consists of a transmitter mounted on a solid plastic frame producing a low-frequency electromagnetic field. The position and orientation of the sensor in the field is recorded by the device. These sensors have been used successfully by many authors to measure spinal motion.[20-22] They have the potential to be used to track the curvature of the spine.

The present study examined the feasibility of using the electromagnetic sensor to track thoracolumbar curvature of the spine. It is possible that some of the inconsistencies in observations discussed earlier, apart from biological variations, are caused by the lack of a reliable measurement protocol. It is hoped that controversies in literature could be addressed by using the method developed in this study.

The purpose of this study was (1) to assess the intratester reliability of a new biplanar method of thoracolumbar curvature measurement by using an electromagnetic tracking device and (2) to examine the effects of aging on the thoracolumbar curvature.

List of Abbreviations

CI	confidence interval
ICC	intraclass correlation
PSIS	posterior superior iliac spine
SEM	standard error of measurement

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No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit on the authors or on any organization with which the authors are associated.

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0003-9993/10/9101-00294$36.00/0
doi:10.1016/j.apmr.2009.08.145

Table 1: Demographic Characteristics of the Participants

Group	Younger (10 males, 16 females)		Older (10 males, 16 females)		Difference
	Mean ± SD	95% CIs	Mean ± SD	95% CIs	P
Age (y)	27.96±5.24	25.84 to 30.08	72.11±5.90	69.72 to 74.50	0.00*
Body mass index (kg/m^2)	22.48±2.51	21.49 to 23.50	24.07±2.68	22.99 to 25.15	0.03*
Thoracic kyphosis (deg)	−38.82±9.86	−42.80 to −34.83	−46.95±11.41	−51.56 to −42.34	0.008*
Lumbar lordosis (deg)	30.37±8.33	27.00 to 33.68	27.11±12.88	21.90 to 32.31	0.28
Lateral thoracic curvature (deg)	0.12±7.27	−2.06 to 4.02	0.97±7.88	−2.20 to 4.16	0.69
Lateral lumbar curvature (deg)	0.83±3.49	−0.59 to 2.24	0.63±4.64	−1.24 to 2.51	0.88

NOTE. Sign convention for curvatures: for the sagittal curvatures, lordosis is defined as positive and kyphosis as negative, and, for the lateral curvatures, convex to the left is defined as positive and convex to the right as negative.
*$P<.05$.

METHODS

Participants

Fifty-two healthy participants were recruited from the staff and students of the University of Brighton and the local community. These participants were divided into 2 equally sized groups based on age. The younger group was aged from 20 to 35 (10 men, 16 women), and the older group was aged 65 and above (10 men, 16 women). The demographic characteristics of the participants are reported in table 1. The means ± SDs of the younger and older age groups were 27.96±5.24 and 72.11±5.90, respectively.

Participants were excluded if they had any history of current back pain or back pain requiring medical attention in the last 6 months; serious trauma leading to fractures or dislocations of the spine; previous surgery of the back; or any pathologies such as tumors, spinal infections, tuberculosis, inflammatory joint diseases, and rheumatologic conditions. They were also excluded if they had any known spinal deformities such as scoliosis, spondylolisthesis, spondylolisis and any neurologic deficits and if they were taking prescribed medications that potentially affect the musculoskeletal system, such as corticosteroids.

Ethical approval for the study was obtained from the Faculty Research Ethics and Governance Committee of The University of Brighton. Informed written consent was obtained from all participants.

Electromagnetic Tracking of Spinal Curvatures

The thoracolumbar curvature was recorded by using an electromagnetic tracking device (Fastrak[a]). Before the data collection, the examiner palpated and marked the vertebral spinous processes and both the left and right PSISs. A small plastic probe (4cm in length) was attached to the electromagnetic motion sensor by using plastic screws. The assessment of the thoracolumbar curvature was performed with the participants standing in their usual relaxed standing posture. The curvature of the spine was traced and recorded by moving the tip of the probe along the skin overlying the spine between the first thoracic and the third sacral spinous process level. A computer program was written to calculate the position of the tip of the probe based on the position and orientation of the sensor. To relate the curvature to specific body landmarks, locations of the following landmarks were digitized by using the probe: T1, T8, L1, and L5 spinous processes and both the left and right PSISs. No special instruction was provided about how the participants should stand so as to record the natural spinal postural curve. Participants were requested to "stand as still as you can in your normal relaxed way, looking forward with your knees straight and your arms hanging by your side." However, foot placement distance was standardized to 20cm apart because this was found to be the most comfortable position in our pilot study.

All measurements were taken 3 times consecutively by the same examiner to establish the repeatability of the data. First, digitized points were transformed from the global coordinate system of the Fastrak source to a local coordinate system fixed to the pelvis (fig 1). This local system was established by using the landmarks PSISs and T8 with the origin as the midpoint between the 2 PSISs. The local coordinates of the thoracolumbar curvature were then fitted with fifth-order polynomial equations, and the tangents at the first thoracic, first lumbar, and fifth lumbar were deduced by determining their derivatives. The magnitude of the angles of the thoracic kyphosis and the lumbar lordosis were determined from the angles between these tangents. Thoracic kyphosis was defined as the angle between the intersections of the tangents at the spinous processes of the first thoracic and the first lumbar vertebrae (see fig 1). The lumbar lordosis was defined by using the tangents at the spinous processes of the first and fifth lumbar vertebrae (see fig 1). This process was repeated in the coronal plane so that the lateral curvatures in the thoracic and lumbar region could be determined. For the sagittal curvatures, lordosis is defined as positive and kyphosis as negative, and, for the lateral curvatures, convex to the left is defined as positive and convex to the right as negative. All calculations were performed by using MatLab.[b] Figure 1 shows an example of the thoracolumbar curvature of one of the participants plotted in 3-dimensional space with the anatomic landmarks identified and how the various curvatures were obtained using the tangents.

Statistical Analysis

Data were analyzed by using SPSS software version 15.[c] $ICC_{1,1}$, based on the 2-way mixed model and consistency type, was performed for data obtained in the 3 repeated measurements, along with the 95% CIs and SEM. Differences in the thoracolumbar and lateral curvatures between the 2 subject groups were compared by using an independent sample *t* test.

RESULTS

Intratester Reliability

The ICC values for the 3 average measures of spinal curvatures are shown in table 2. The reliability of measurements of spinal curvatures with this technique was good to excellent. The ICC for kyphosis was 0.93 with a 95% CI of 0.88 to 0.95 and an SEM of 1.57°. Lumbar lordosis measurements had better reliability results with an ICC of 0.98 (0.96–0.98) and an

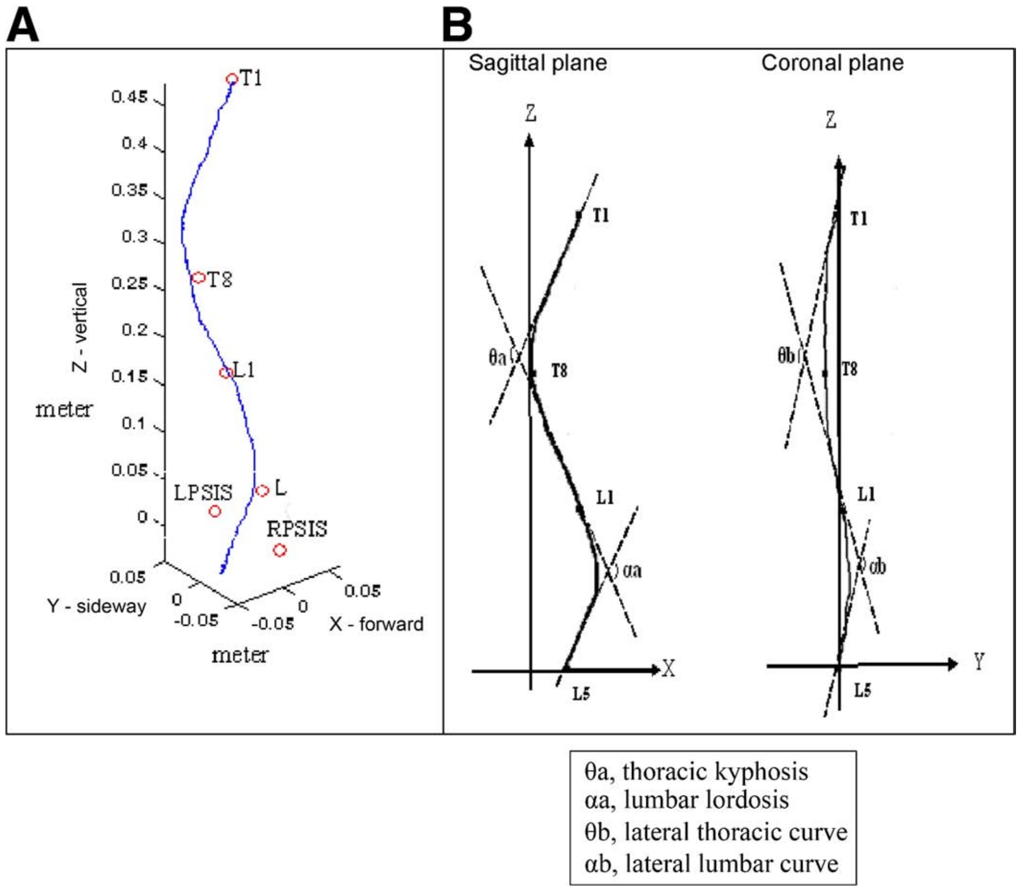

Fig 1. Biplanar measurement of thoracolumbar curvature: a computer output and measurement method. (A) Thoracolumbar curvature in 3 dimensions. (B) Measurements of the thoracolumbar curvature. Abbreviations: LPSIS, left posterior superior iliac spine; RPSIS, right posterior superior iliac spine.

SEM of 1.51°. The lateral curvatures for thoracic and lumbar regions had ICCs of 0.75 and 0.85, respectively.

Effects of Aging on the Thoracolumbar Spinal Curvatures

The descriptive statistics of participants are shown in table 1. The mean thoracic kyphosis (−46.95°±11.41°) in the older adults was significantly larger than that in the younger adults (−38.82°±9.86°) ($P<.01$). No statistical difference was noted for the lumbar lordosis between the younger and older age group ($P>.01$) (fig 2). In regard to the coronal plane, both the groups did not exhibit any significant lateral curvature (scoliosis). There were no significant differences in the lateral curvature between the 2 groups ($P>.01$) (see fig 2).

DISCUSSION

This study presents a new and innovative method of measurement of the thoraolumbar curvature in the sagittal and coronal planes. The data obtained were found to be highly reliable, and it is suggested that the method could be used for everyday clinical practice if further modifications are made. The current method involves the use of MatLab software and polynomial curve fitting, which may not be readily understood and accepted by clinicians. However, a commercial computer program may be written to perform all these tasks so that it is user-friendly for the clinicians. The current method is clinically attractive because it is noninvasive and does not involve the use

Table 2: ICCs of the 3 Measurements of Thoracolumbar Curvature

Spinal Curvatures	ICC	95% CIs Lower	95% CIs Upper	SEM
Thoracic kyphosis	.93	.88	.95	1.57°
Lumbar lordosis	.98	.96	.99	1.51°
Lateral curvature at thoracic region	.75	.61	.85	1.04°
Lateral curvature at lumbar region	.84	.85	.91	0.56°

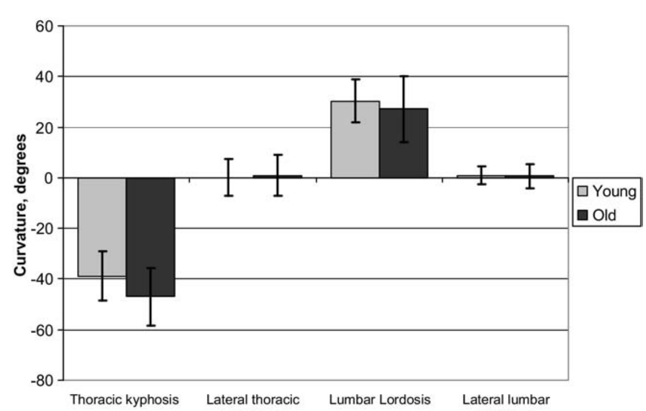

Fig 2. Sagittal and lateral curvatures of the thoracolumbar spines of the younger and older participants.

Table 3: Thoracolumbar Curvature Measurements Reported in the Literature and the Results of the Present Study

Authors and Participants	Method	Thorocic Kyphosis Angles (°) Mean ± SD	Lumbar Lordosis Angles (°) Mean ± SD
Present study	Fastrak	T1–L1	L1–L5
Younger group (n=17, aged 20–35)		−38.82±9.86	30.37±8.33
Older (n=17, aged≥65)		−46.95±11.41	27.11±12.88
Mannion et al, 2004[18] (n=20, age: 41±12)	Spinal mouse	T1-2 to T11-12	T12-L1 to S1
		45	32
Mannion et al, 2004[18] (n=103, age: 19–59)	Fastrak	T1–L1	L1–S1
		43±13	30±NA
Harrison et al, 2001[16] (n=30, age not available)	X-ray	NA	L1–L5
			34.5±14.8
Hammerberg and Wood, 2003[4] (n=50, age: 70–85)	X-ray	T1–T12	L1–S1
		52.5±12.2	57.4±13.7
		(29–79)	(20–96)
Keller et al, 2005[15] (n=67, age: 26.7 (4.8)	X-ray	T1–T12	T12–S1
		43.7±11.4	67.4±12.6

Abbreviation: NA, not applicable.

of radiation. The cost of the system is still small compared with the radiographic method and the video-based motion analysis system.

Wide variations in thoracic kyphosis and lumbar lordosis values were observed in the present study (table 3). Earlier studies[4,23] also reported considerable variations in the elderly populations· These variations may be attributable to (1) differences in measurement technique and equipment used, (2) physical and anthropometric differences in the participants, (3) different numbers of participants, (4) different percentage of sex distribution in the sample, (5) different ages of the sample group, and (6) different levels of measurements in the studies.

When using the spinal mouse for measuring the thoracolumbar curvature,[18] the mean thoracic kyphosis was found to be 43°±13°. These measurements were taken from the T1 to the L1 spinous processes of the vertebrae. They also reported that the mean lumbar lordosis was 30°, as measured from L1 to S1. These curvature values were very similar to those observed in the present study. The details of the measurement technique were not provided in this earlier study. The spinal mouse comprised an electromagnetic sensor, but it did not appear that a probe was used. On the other hand, in the current investigation, the very small tip of the probe had allowed us to obtain much more precise curvature measurement. The SEM was found to be 3° when using the spinal mouse method,[18] whereas, in the present investigation, the SEM was much smaller (1.57° for thoracic kyphosis and 1.51° for lumbar lordosis).

In addition, the present measurement technique had excellent intratester reliability with an ICC of more than .90 for the sagittal curves and .75 for lateral curvatures. The lateral curvature in the normal spine of this study was close to 0, and this shows that the instrument was still highly reliable for extremely small curvatures. The present method of thoracolumbar curvature measurements is considered to be reliable enough for both research and clinical purposes. In addition, the mean error of measurement was reported to be 0.6° to 4.5° in previous x-ray measurements,[9,16] and, thus, the present method was as reliable as the radiographic method.

The present study showed an increase in thoracic kyphosis angles in healthy adults with aging, supporting the results of earlier studies.[4-10] However, no significant difference was observed in the lumbar lordosis angles between the younger and older participants. Similarly, several other authors were unable to establish an association between age and lumbar lordosis in their studies.[4,11-13] These observations could be explained anatomically. Vertebral deformities in the elderly population, such as anterior wedging of the vertebral body, were found to be much more common at the thoracic levels than the lumbar levels.[24,25] Such wedging deformity would lead to a decrease in the anterior height of the vertebral body and, thus, an increase in thoracic kyphosis. In addition, aging was found to be associated with a decrease in the anterior disk height of the thoracic spine, which might also contribute to the increase in kyphosis, but the contribution of the disk to the curvature was found to be less when compared with that of the vertebra.[26] However, in the lumbar region, the age-related changes were found to be very different. There were generally increases in disk height and concavity of the lumbar vertebrae,[27] but these changes tended to be similar in the anterior and posterior aspects of the spine and did not appear to alter the lumbar curvature.

Mechanically, increased thoracic kyphosis will position the trunk in a more flexed position and shorten the moment arm of the trunk extensor musculature.[2] Hence, the ability of these muscles to generate torque may be compromised. To produce the same torque, the contraction of the muscles needs to be increased, leading to larger compressive force on the spine.[2,15] These changes in mechanics may be related to the occurrence of vertebral fractures in older spines that are osteoporotic.[28] The compromised muscle function may also lead to decreased functional performance[29] and poor balance control and falls[30,31] in older adults.

Study Limitations

One limitation of the present method was that it did not measure axial twisting of the trunk to provide a true 3-dimensional picture. This is particularly important in the assessment of scoliosis deformity in young children because twisting is a major component of such deformity. To assess spinal curvatures in 3 dimensions, previous studies have used techniques like Moirè topography,[32] but the method is too time-consuming and complicated for clinical use. Therefore, the present technique provides the best compromise with biplanar measurements. For the purpose of the present study, it is considered that the biplanar measurement of curvatures in the sagittal and coronal planes is sufficient to assess the effects of aging. Deformities associated with aging usually occur in these planes.[4,6-8,23]

Another limitation of the present work was that it did not look at the validity of the curvature measurements. This was beyond the scope of the present study and would require comparison with a criterion standard. Radiographic and magnetic resonance images have previously been used for comparison,[9,33] but these involve radiation and may not be ideal gold standards because they are subjected to errors.[34] Previous research[35] has shown that the spinous processes can be easily identified and accurately marked on the skin, and such accuracy is essential to any surface measurement of spine curvature. It was reported that the correlation between radiographic and skin surface measurements of spine curvatures was excellent (r=.94 for thoracic kyphosis and r=.91 for lumbar lordosis).[33] The mean differences in measurements of the thoracic and lumbar curves were only $5° \pm 4°$ and $6° \pm 6°$, respectively.[33] Hence, the curvature of the skin overlying the spinous processes was a valid estimate of the curvature of the vertebrae. As discussed earlier, the curvature values observed in the present study compare favorably with those reported in earlier works (see table 3). This also supports the face validity of the measurement method presented in this study.

CONCLUSIONS

The measurement of spinal curvatures is an important part of clinical evaluation of spinal disorders such as low back pain and spinal deformities. It is concluded that a probe attached to an electromagnetic motion sensor is a highly reliable and innovative method of biplanar measurement of spinal curvatures. This study provides evidence of an increase in the thoracic kyphosis with aging, although there was no difference in the lumbar lordosis between the younger and older adults.

Acknowledgments: We thank Ann Moore, PhD, and the staff at Clinical Research Center for providing support in carrying out this study.

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