A comparison of three methods for measuring thoracic kyphosis: implications for clinical studies

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Abstract

Objectives. To compare the Cobb technique for measuring kyphosis with an alternative Cobb method and a computer-assisted curve assessment technique, and to examine the influence of vertebral body and disc shape on kyphosis.

Methods. Kyphosis measurements were derived from 93 lateral spinal radiographs or sagittal computed tomography images of cadaveric spines, using: (i) a computer-assisted method for estimating radius of curvature; (ii) the traditional Cobb method; and (iii) an alternative Cobb method. Regression models were applied for agreement analyses, and to examine the relative contribution of vertebral body and disc shape on the extent of curvature.

Results and conclusions. Strong associations existed between curvature and angle data derived from the three methods, confirming the clinical utility of these techniques for the quantification of thoracic kyphosis. However, the traditional Cobb method tended to overestimate kyphosis in the presence of vertebral body end-plate deformation. The degree of kyphosis was strongly reflective of the extent of deformity of the vertebral bodies, and to a lesser extent the shape of the thoracic discs.

Key words: Thoracic spine, Kyphosis, Cobb angle, Computer-assisted measurement, Vertebral body, Intervertebral disc, Spinal curvature.

Age-related progression of the thoracic sagittal curve is commonly accentuated in spondyloarthropathies such as ankylosing spondylitis [1], and in conditions such as spinal osteoporosis and Scheuermann’s disease [2, 3]. Radiographic assessment of the thoracic spine is the standard for examination of spinal kyphosis, as indicated by the traditional Cobb angle [4] (Fig. 1). The angle is derived from the slope of selected vertebral end-plates, which also provides objective measurement of frontal plane spinal deformity in scoliosis. As the Cobb method is influenced by the orientation of vertebral end-plate tilt, the derived angle may not fully reflect the actual curve characteristics [5–9]. Numerous studies have defined thoracic curvature properties using alternative measurement techniques that are independent of end-plate tilt [9–12]. In studies of the scoliosis deformity, systematic discrepancies in curvature derived from the traditional Cobb method compared with the angle derived along the line of vertebral bodies have been demonstrated, despite high correlation coefficients between methods [9, 12]. These findings reiterate the importance of defining the level of agreement between measurement methods, beyond merely providing an estimate of the magnitude of correlation between two sets of data.

Additionally, the poor reproducibility of Cobb angle measurement commonly raises uncertainty about the validity of identified changes or progression in curvature [13–15]. The ability to distinguish between true change and measurement error is critical in the prospective clinical evaluation and management of postural deformity. Recent developments in computer-assisted methods have enabled the evaluation of spinal curves with greater accuracy and lower measurement error compared with manual techniques [5, 7, 8, 14, 16]. From a clinical perspective, these benefits may provide more reliable and valid means of monitoring changes in spinal curvature, with the primary aim of minimizing further progression of spinal deformities. For example, the role of interventions to arrest the progression of spinal...
Comparison of three methods of kyphosis measurement

Fig. 1. (A) Thoracic kyphosis represented by the traditional Cobb angle and an alternative version. Traditional Cobb: perpendiculars were extended from lines drawn through superior landmark markings of T4 and inferior markings of T9. The resulting angle was measured from the intersection of the two perpendiculars. Alternative Cobb: a line was extended through the mid-points of the superior and inferior end-plates of T4, and similarly for T9 (see enlargement). The angle was derived at the point of intersection of the lines. (B) An illustration of the technique for deriving mean radius of curvature. (C) The arcs were smoothed and averaged to produce a single curve with a mean radius of curvature, measured in millimetres.

deforrmity requires precise outcome measures to determine their efficacy.

Various studies on the thoracic kyphotic deformity have been accompanied by morphological investigations examining shape features of the thoracic vertebral bodies, and to a lesser extent, the intervertebral discs, to enable an understanding of their potential influence on the development of kyphosis [17–21]. In view of some of the technical limitations associated with in vivo radiographic methods, Edmondston et al. investigated thoracic spine curvature from an ex vivo perspective [22, 23]. Studies of this nature afford greater accuracy and reliability in the selection of measurement landmarks for the quantification of shape parameters [24]. The validation of ex vivo measurement of thoracic kyphosis against in vivo spinal radiographs, using computer-aided and traditional Cobb methods has been documented previously [16].

The objective of the present study was to examine the thoracic kyphosis, between T4 and T9, from post-mortem spinal radiographs using the traditional Cobb method, and to compare curvature measurements against two methods which are independent of vertebral end-plate orientation: (i) a computer-assisted method for deriving radius of curvature; and (ii) an alternative Cobb method. The extent to which age, vertebral body shape, and disc shape influenced the magnitude of kyphosis derived from each of the different methods was also investigated.

Methods

Potential cases were selected from a database of post-mortem sagittal computed tomography (CT) thoracic scans and lateral spine radiographs. Columns with evidence of marked bony pathology, severe osteophytes, scoliosis, vertebral fracture, or poorly defined vertebral margins were excluded. Post-mortem archives were reviewed to exclude cases with a history of metabolic disease, neoplasm or trauma. A total of 93 cases was selected, comprising lateral view contact radiographs of 51 hemisected and 30 intact cadaveric spines, and mid-sagittal CT scans of 12 cases utilized in a previous study [22]. There were 35 female and 58 male cases. The mean age was 58.8 yr (s.d. 21.6, range 15–95). Only the mid-thoracic region between T4 and T9 was considered for the present study, as the majority of osteoporotic-related fractures occur in this region of the spine [19]. Furthermore, vertebrae at these levels were clearly discernible in all cases.

Using an electronic digital calliper (NSK, Max-Cal, Japan Micrometer MFG. Co., Ltd, Osaka, Japan), anterior and posterior vertebral body and intervertebral disc heights were measured from corner landmarks marked on tracing paper superimposed on radiographic films [25]. Vertebral body and disc shape were represented by the anteroposterior (A/P) height ratio, which described the extent of anterior wedge deformation. The degree of thoracic kyphosis between T4 and T9 was estimated by the traditional Cobb angle [4], and an alternative version of the Cobb method which is less influenced by vertebral end-plate tilt (Fig. 1A).

The same segmental levels were used for the analysis of radius of curvature using a computer-assisted method [5, 16]. (Further information regarding software developed for this study may be requested from the authors.) Anterior and posterior vertebral margins were outlined by connecting corner landmarks. The tracings were then positioned on a digitizing tablet (Digipad 5, GTCO, Rockville, MD, USA), which was linked to a PC. Both the anterior and posterior vertebral margins were digitized continuously (Fig. 1B), smoothed, and averaged to produce a single arc, from which the mean radius of curvature (mm) was derived between the superior border of T4 and the inferior border of T9 (Fig. 1C). Spines exhibiting a greater degree of kyphosis produced a higher Cobb angle and, correspondingly, a shorter radius of curvature.

The associations between radius of curvature data, Cobb angles and independent variables (age, vertebral body and disc shape) were analysed using simple linear regression. To examine the reliability of the three methods for measuring kyphosis, repeated measurements were performed on 15 cases selected at random. Each measurement technique was applied to five cases and was repeated five times over the course of 1 month. Reliability indices were described by the intraclass correlation coefficient (ICC) calculated from repeated measures analysis of variance (ANOVA), and the coefficient of variation (CV), which also provided an estimate of the spread of measurement variability.

Potential errors due to radiographic magnification were examined by taking contact radiographs of one hemisected vertebral column, with a nominated vertebra

311
S. Goh et al.

312

first positioned at the centre of the X-ray beam, then at 10 and 20 cm from the central projection of the X-ray beam. Corner landmarks from the selected vertebral body were traced 10 times for each of the three image positions. Vertebral body heights were measured as described previously. Vertebral height differences between the three imaging positions were examined using ANOVA. For all analyses, a probability level of $P < 0.05$ was adopted as the criterion for accepting statistically significant differences.

Results

Kyphotic angles derived from the traditional Cobb method were highly associated with the alternative method ($r^2 = 0.98; n = 93; P < 0.0001$; Fig. 2). The mean difference (s.d.) between the two angles, calculated by subtracting the alternative Cobb angle from the traditional Cobb angle, was 1.6° (4.1°) (range −7.0° to 18.5°). In five cases (illustrated in Fig. 2 by filled circles), the difference ranged between 9° and 18.5°. These values represented a difference greater than +2 s.d. between the two angles. For all five cases, the examination of the vertebral segments indicated T4 A/P vertebral height ratios ranging between 0.73 and 0.85, which corresponded to the five lowest values for that vertebral segment. Ranking of the T4 A/P height ratios provided 100% sensitivity and specificity for the classification of outliers relating to the comparison of the two Cobb methods. Thus, for cases demonstrating T4 A/P ratios greater than 0.85, the difference between Cobb angles was always within +2 s.d. of the mean. The resulting mean difference between Cobb angles for the subsequent 88 cases was 0.9° (2.9°) (range −7.0° to 6.0°).

A least squares best fit model was used to compare the mean radius of curvature data against the Cobb angles. Logarithmic regression models fitted to the data set demonstrated high associations of mean radius of curvature with both the traditional and alternative Cobb angles ($r^2 = 0.81$ and $r^2 = 0.84$, respectively; Fig. 3). However, at lower Cobb angles, there was a trend for greater dispersion of data points around both regression lines.

To satisfy assumptions of normality, a log transformation of mean radius of curvature data was applied prior to further statistical analysis [26]. Comparison of the transformed radius of curvature data with the Cobb angles using linear regression models demonstrated high

![Fig. 2. The traditional Cobb method for measuring T4–T9 kyphosis in 93 ex vivo lateral spine radiographs and CT images was strongly correlated with an alternative Cobb method. Poor agreement between methods was noted for a number of cases, represented by filled data points, where the difference between Cobb angles (alternative Cobb angle subtracted from traditional angle) was greater than +2 s.d. of the mean. These data points represented cases with accentuation of anterior vertebral wedging of the T4 segment (A/P ratio ≤ 0.85).](https://academic.oup.com/rheumatology/article/39/3/310/1783798)

![Fig. 3. Regression plots demonstrating strong associations between computer-derived mean radius of curvature and (A) the traditional Cobb angle and (B) an alternative Cobb angle, measured from 93 ex vivo spinal radiographs and mid-sagittal CT images (T4–T9).](https://academic.oup.com/rheumatology/article/39/3/310/1783798)
Discussion

Limitations associated with the reliability and validity of the traditional Cobb method have raised doubts regarding its clinical utility as an accurate indicator of kyphotic and scoliotic deformities. In this study, kyphotic Cobb angle measurements from post-mortem spines were compared against a computer-aided method and an alternative Cobb method. This ex vivo study was undertaken to minimize potential errors associated with in vivo radiographic methods, and to enable interpretation of thoracic kyphosis data in relation to shape features of the thoracic vertebral bodies and intervertebral discs [22, 24].

A high reproducibility was shown for all three methods. For both Cobb methods, the 95% confidence interval for intra-observer measurement variability was less than 2°, compared with values ranging from 3.3° to 11° for repeated Cobb angle measurement from in vivo spinal radiographs [7, 13–15]. Measurement errors have been attributed to inconsistent selection of vertebral
correlations with the manually derived traditional Cobb angle and the alternative Cobb angle ($y = 2.94–0.015x$, $r^2 = 0.76$ and $y = 2.95–0.017x$, $r^2 = 0.83$, respectively). Comparison of both regression models using analysis of covariance (ANCOVA) indicated no significant differences in intercepts or regression slopes.

Age was moderately correlated with all three indices of kyphosis (Table 1). Strong associations were noted between kyphosis and vertebral body shape, while disc shape was poorly associated with kyphosis. Correlation coefficients for the computer-assisted and alternative Cobb methods were similar.

High indices of reliability were noted for repeated curvature measurements derived from all three methods (computerized method: CV 4.5%, ICC 0.95; traditional Cobb: CV 3.4%, ICC 0.82, s.d. 0.87; alternative Cobb: CV 4.1%, ICC 0.97, s.d. 0.83). Examination of the effects of radiographic magnification on vertebral body heights demonstrated no significant differences in anterior or posterior heights, measured from repeated tracings of a selected vertebral body imaged in three separate positions. The mean (s.d.) anterior and posterior heights were 17.4 mm (0.1) and 18.3 mm (0.2), respectively.

**Table 1. Correlation coefficients describing the relationships between three indices of kyphosis with age, vertebral body shape and disc shape for 93 post-mortem spines**

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Age</th>
<th>Vertebral body shape</th>
<th>Disc shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Cobb angle</td>
<td>0.47***</td>
<td>-0.80***</td>
<td>-0.22*</td>
</tr>
<tr>
<td>Alternative Cobb angle</td>
<td>0.54***</td>
<td>-0.64***</td>
<td>-0.35***</td>
</tr>
<tr>
<td>Computer-derived radius of curvature (transformed data)</td>
<td>-0.56***</td>
<td>0.65***</td>
<td>0.31***</td>
</tr>
</tbody>
</table>

$*P < 0.05; **P < 0.005; ***P < 0.0001$.
The advantages associated with computer-assisted methods may also justify its clinical application, despite the added requirements of a PC and related equipment. While comparison of linear regression models of the transformed radius of curvature data against Cobb angle data indicated similarity of the linear comparisons, suggesting that all three methods are essentially equivalent, the limitations of the traditional Cobb method remain. Clinical studies have demonstrated improved reliability and accuracy of computer-aided curve assessment compared with the manual Cobb method [5, 7, 8]. Computer modelling of sagittal curvature may be adapted such that unique features of the thoracic curve (the location of the kyphotic apex and curve inflection points) may be investigated [16]. These benefits have potential for prospective studies of spinal deformity in conditions such as ankylosing spondylitis [1], osteoporosis [2], and Scheuermann’s disease [3]. Furthermore, the storage of data in a digital format enables clinicians to monitor spinal curve progression from serial studies. The poorly defined associations between radius of curvature and Cobb angle data at Cobb angles of less than 20° (Fig. 3) confirm the limitation of the computerized method for defining spinal curvature in columns exhibiting minimal kyphosis. However, the clinical implications may be of little significance, given that kyphotic deformities that warrant medical attention are typically larger in magnitude.

Thoracic sagittal curvature derived from all three methods was significantly associated with age, vertebral body shape, and disc shape. The age-related progression in kyphosis may be attributed to osteopenia [2], loss of muscular tone, occupational and habitual posture [10], and alterations in vertebral body shape [22]. The role of vertebral body remodelling and its association with thoracic kyphosis has been well documented in osteoporosis-related studies. Little is known, however, about the influence of the thoracic discs in determining kyphosis. The results from the present study suggest involvement of the thoracic discs in this regard, although their role appears to be minimal, a finding reported in the literature [17, 27, 28]. This observation has been noted as early as the adolescent period, during which the development of juvenile kyphosis is partly attributed to losses in anterior disc height resulting from intravertebral herniation of disc material through the vertebral endplates, as in Scheuermann’s disease [28]. Indeed, alterations in disc shape may represent part of the spectrum of normal ageing, with these changes partly accounting for progression of kyphosis across the life span.

In conclusion, this study has demonstrated strong associations between three measurement methods for the ex vivo quantification of thoracic sagittal curvature. Vertebral body shape was strongly correlated with all kyphosis indices. The computer-aided and alternative Cobb methods appear more appropriate for examination of thoracic kyphosis in cases exhibiting irregularities in vertebral end-plate orientation.

Acknowledgements
The authors wish to acknowledge Livio Mina and Rob Day from the Medical Physics Department for programming assistance, Professor B. Kakulas from the Department of Neupathology, Professor T. H. M. Chaker from the Department of Imaging Studies, Royal Perth Hospital, for access to departmental resources, and Dr J. Sommer, Curtin University of Technology, for statistical advice. This work was funded through the NH & MRC (970244).

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