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Original Research

The Reliability of the Projection Area Per Length Squared for Measuring Lumbar Lordosis on Lateral Radiographs: A Comparison with Cobb Method

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ABSTRACT
Objective: The assessment of the degree of lumbar lordosis in patients with spinal disorders is essential to determine disease progression and the effectiveness of treatment. The aim of this study was to examine the reliability of the projection area per length squared (PAL) for measuring lumbar lordosis on lateral radiographs and to compare it with the Cobb method.
Methods: Two independent investigators measured lumbar lordosis twice on 100 lateral radiographs using PAL and Cobb methods. Intra- and interobserver agreements of each radiological method were evaluated using intraclass correlation coefficients (ICC) and Bland–Altman plots. Correlations between the PAL estimations and Cobb angle measurements were tested using the Spearman rank correlation coefficient.
Results: Intra- and interobserver agreements for PAL and Cobb methods were excellent with all ICC values>0.976. The Bland–Altman plots indicated strong intra-observer and interobserver concordance in the measurement of the lumbar lordosis using the PAL method. A strong correlation was determined between the PAL and Cobb angle values in the first and second measurements (r=0.825; p<0.001 and r=0.815; p<0.001, respectively).
Conclusion: The PAL technique is easy to apply on digital images and provides quantitative information independent of the vertebral surface pathologies of the end vertebrae. It could be used as an alternative and potent diagnostic criterion for evaluating lumbar lordosis.
Keywords: Cobb angle, length squared, lumbar lordosis, planimetry, radiography

INTRODUCTION

Lumbar lordosis is a crucial structural component of the human spine in maintaining sagittal spinal alignment (1, 2). Ideal sagittal alignment in the lumbar region of the spine or normal lumbar lordosis is the primary goal for clinicians in surgical, ergonomic, and physiotherapeutic interventions (3). Therefore, physicians routinely measure and evaluate the lumbar curvature in the management of spinal deformity. Measurements of lumbar lordosis can provide quantitative data for monitoring disease progression or evaluation of the surgical approaches designed to restore the lordosis (4, 5). Therefore, appropriate and reliable measurement of the lumbar lordosis is important for clinical decisions.

Various techniques have been developed over the years for the quantitative evaluation of lumbar lordosis (1). Most of the existing methods are based on angle measurements formed by drawing straight lines from different landmarks of the lumbar vertebrae (1,5). The Cobb method, one of the first methods, is regarded as the gold standard for measuring lordotic curvatures on two-dimensional images in clinical practice because it provides the practical and rapid measurement of the sagittal spinal curvatures (6, 7). However, the Cobb method has some limitations, which can increase the variability in Cobb angle measurements (1, 8). In consideration of the limitations of the Cobb angle measurements, several alternative methods have been described by investigators to overcome these limitations (9). Suggested methods have involved multiple steps, used non-standardized terminology, and different anatomic landmarks when examining lumbar lordosis, so these methods are not widely used in clinical practice (9, 10). A more objective and standardized method is required for accurate and reliable measurement of lumbar lordosis.

The aim of this study was to describe an alternative approach for quantifying the degree of lumbar lordosis on lateral radiographs and to compare it with the Cobb method.

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METHODS

Study Design

Before the present study that is designed as a retrospective study commenced, approval was obtained from the local ethics committee of our institution (Decision Date: 2021 Approval No:436). A total of 100 standing lateral lumbar radiographs from 50 males and 50 females with varying degrees of lumbar lordosis were randomly selected between 2010-2019 from the archives of the Radiology Department of Hitit University, Çorum, Turkey. Patients with spinal deformity, cauda equina syndrome, previous back surgery, and spinal tumors were not included in the present study. All X-rays had previously been assessed for eligibility.

Two investigators with different levels of measurement experience were involved in this study. Investigator 1 had six years of experience using the PAL technique and four years of experience using the Cobb method. Investigator 2 had no measurement experience with either the PAL or the Cobb methods. As investigator 2 was unfamiliar with both the PAL and Cobb methods training was given on twenty digital radiographs for each measurement method before the study.

Radiographic Measurements

PAL Method

The planimetry technique was used to estimate the PAL of lordotic curvature on the digital images. Planimetry, which is based on the manual delineation of the margins of objects of interest on image sections, is the most widely preferred method for surface area measurement of irregularly shaped structures (11). All digital images were stored in the “Digital Imaging and Communications in Medicine (DICOM)” format. All measurements were performed using ImageJ software (Version 1.48, National Institutes of Health, Bethesda, Maryland, USA). The PAL estimation of lumbar lordosis on digital images was applied as follows.

The superoposterior corner of the first lumbar vertebra and the inferoposterior corner of the lower end vertebra were marked as anatomic bony landmarks. These landmarks were then connected with a straight line (Figure. 1A). The posterior boundaries of five lumbar vertebrae between the superoposterior and inferoposterior corners were drawn along the curvature, and the upper and lower ends of the elliptical-shaped line were connected to the beginning and end of the straight line. Finally, a semilunar area was obtained on the posterior side of the curvature (Figure. 1B). Both the semilunar region projection area and the length of the straight line were calculated using the ImageJ program (National Institutes of Health, Bethesda, MD, USA). Finally, the PAL was calculated as a percentage using the following formula (Figure. 1C) (12):

Where (*A*) denotes the semilunar region area and (*l*) represents the estimated length of the straight line between the superior and inferior end vertebrae. The PAL of the curvature expresses the surface area proportion of the semilunar area within the projection area of the square, which is the virtual reference surface area obtained from the square of the length (Figure. 1C).

Main Points:

- Projection area per length squared approach could provide accurate and reliable data for measuring the degree of lumbar lordosis.
- Projection area per length squared approach provides quantitative data independent of the vertebral surface pathologies of the reference vertebrae.
- Projection area per length squared approach could be used as an alternative diagnostic criterion for evaluating lumbar lordosis.

Figure 1A. White arrows show the superoposterior corner of the first lumbar vertebra and the inferoposterior corner of the fifth lumbar vertebra.

Figure 1B. Lateral digital radiograph showing the semilunar area drawn for the estimation of the projection area per length squared.

Figure 1C. The PAL of the curvature expresses the surface area proportion of the semilunar area within the projection area of the square, which is the virtual reference surface area obtained from the square of the length.

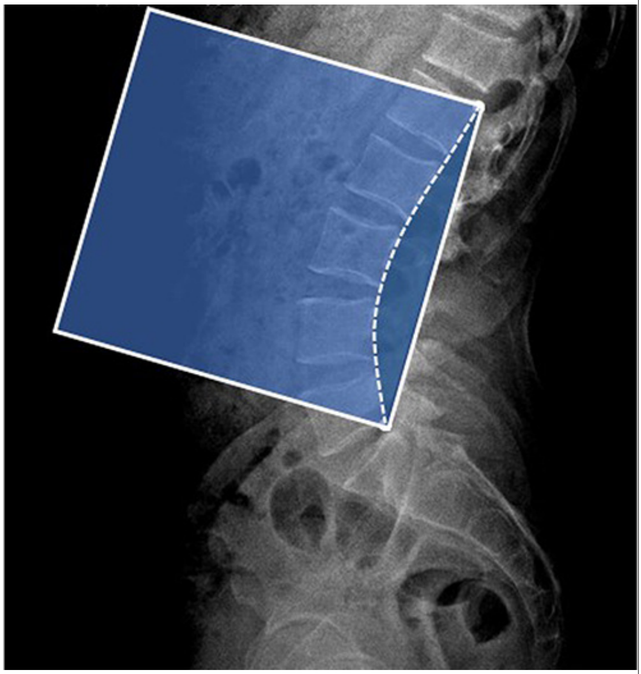
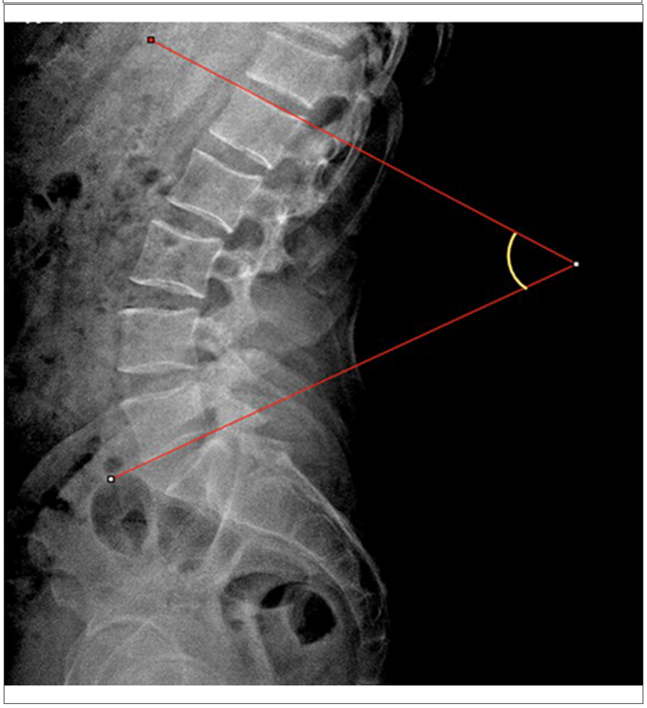


Figure 2. Computer-assisted Cobb angle measurement on lateral radiographs using OsiriX software. Cobb angle was formed by a lines drawn along the upper and lower surface of the first and fifth lumbar vertebrae.



Cobb Method

The Cobb angle measurements were performed using OsiriX software (OsiriX v.3.8.1 32 bit, Pixmeo SARL, Bernex, Switzerland). All digital images were transferred to OsiriX software. After opening the images, the investigators defined the superior and inferior endplates of the first and fifth lumbar vertebrae. Lines were drawn through and parallel to the superior and inferior endplate of the first and fifth lumbar vertebrae using the software tools. Finally, the program estimated the Cobb angle automatically (Figure. 2). The two investigators independently measured the lumbar lordosis on lateral radiographs using the PAL approach and the Cobb method twice at an interval of one month so as to reduce bias. Each investigator was blinded to the results of the other and to their own previous measurements of the same images for each measurement method.

Statistical Analysis

The data obtained were analyzed statistically using the Statistical Package for the Social Sciences for Windows, version 22 software (SPSS, Chicago, IL, USA). Conformity of the volumetric data to normal distribution was tested using the Shapiro-Wilk test. Estimation results obtained with each method were analyzed to detect statistical differences using the Wilcoxon signed-rank test. The intraclass correlation coefficient (ICC) (two-way mixed model) was calculated to define the intra- and interobserver reliability of each technique. The Bland–Altman method was used to examine the consistency between PAL measurements obtained by the two investigators in both sessions. The Spearman correlation test was used to analyze the degree of the relationship between the PAL approach and the Cobb method in both sessions.

RESULTS

The mean age of the subjects was 45.19±13.55 years (min-max, 22-77 years). The mean age of males and females were 47.62±9.44 and 42.76±10.25 years, respectively. There were no statistically significant differences between males and females in age (P=0.224). The overall mean PAL (±SD) obtained by both investigators was 6.23±2.15% (min-max, 2-11.90%). Three subjects with the minimum, medium, and maximum PAL values are shown in Figure 3.

According to the results of the Wilcoxon signed-rank test, there were no significant differences between each investigator's PAL estimation results in the first and second sessions (p=0.187, p=0.782, respectively). There were also no significant differences between the PAL estimation results of the two observers in the first and second sessions (p=0.432, p=0.853, respectively) The details of the PAL measurements of investigators in both sessions are given in Table 1. The ICC showed a high degree of intra-observer agreement in the PAL estimations for the first and second investigators (ICC=0.997, ICC=0.996, respectively). Interobserver agreement of the PAL estimations was found to be almost perfect for the first and second sessions (ICC=0.995, ICC=0.997, respectively).

Figure 3A. Subject with (A) minimum projection area per length squared (2.00%). The PAL value of the subject corresponded to Cobb angles of 11.34°.

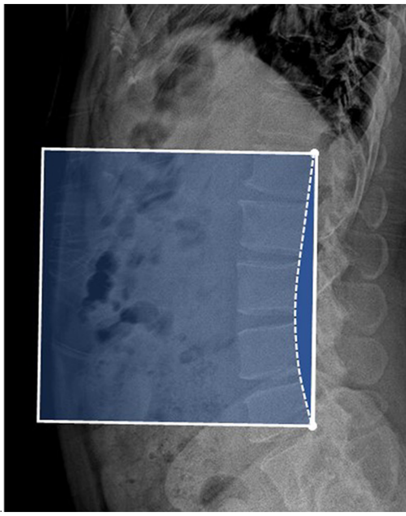


Figure 3B. Subject with (B) medium projection area per length squared (6.30%). The PAL value of the subject corresponded to Cobb angles of 48.45°

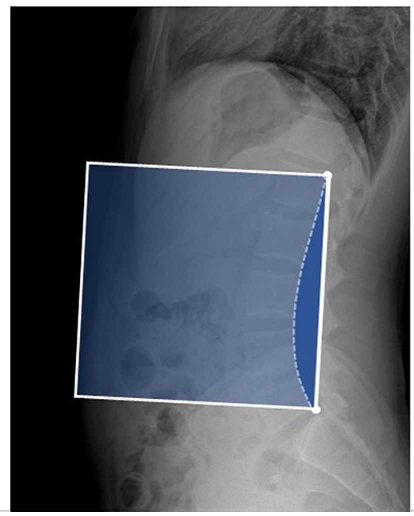
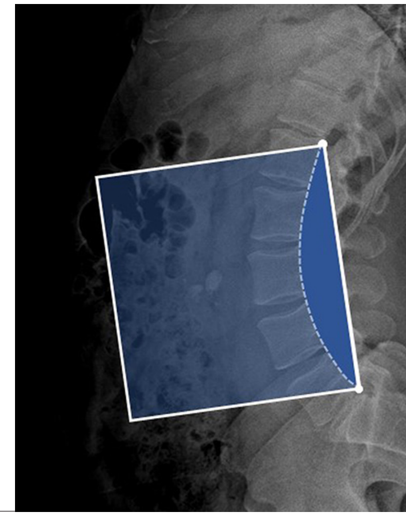


Figure 3C. Subject with (B) maximum projection area per length squared (11.90%). The PAL value of the subject corresponded to Cobb angles of 73.38°.



The Bland–Altman plots showed that the mean PAL estimated by the same investigator in two sessions differed between – 0.47 and 0.41%, and -0.51 and 0.51%, respectively (Figures 4 and 5). There was no significant difference between the repeated measurements of both investigators (p>0.145, p>0.817, respectively). The Bland–Altman blots indicated that the mean PAL estimations of the investigators in both session 1 and session 2 differed by – 0.59% and 0.55%, and -0.43% and 0.45%, respectively (Figures 6 and 7). There was no significant difference between the PAL measurements of the investigators for the first and second sessions (p=0.585, p=0.660, respectively).

The average Cobb angle (±SD) on 100 digital radiographs was 45.27±13.35° (min-max, 11.34-73.38°). Based on the results of the Wilcoxon signed-rank test, no statistical difference was found between the repeated Cobb angle measurements of both investigators (p=0.503, p=0.152, respectively). No statistically significant differences were determined between the Cobb angle measurements of the two investigators in the first and second sessions (p=0.623, p=0.181, respectively). The details of the Cobb angle measurements in both sessions are given in Table 2. The ICC showed a high degree of intra-observer agreement in the Cobb angle measurements of the two investigators (ICC=0.987, ICC=0.989, respectively). Interobserver agreement of the Cobb angle measurements was found to be almost perfect for the first and second sessions (ICC=0.987, ICC=0.976, respectively).

There was a high correlation between the PAL estimations and Cobb angle measurements for the first and second sessions (r=0.825, p<0.001; r=0.815, p<0.001, respectively). The relationship between the PAL estimations and the Cobb angle measurements of both investigators in the first and second sessions are shown in Figures 8-11. According to the estimation results of the measurement methods in both sessions, the PAL estimates had high linear correlations with the Cobb angle measurements.

Figure 4. The Bland–Altman plot showing the differences between the mean PAL obtained by first investigator in the first and second sessions. The dashed line represents 95% limits of agreement.

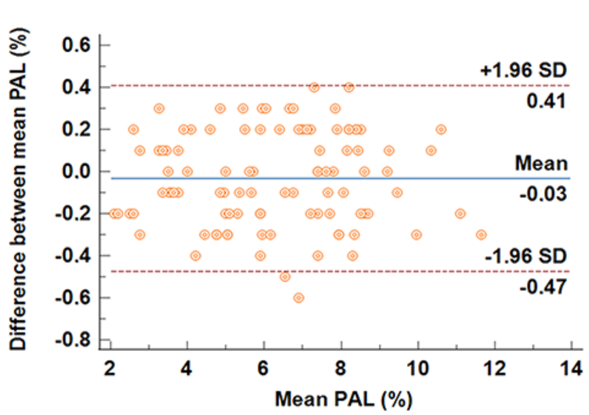


Figure 5. The Bland–Altman plot showing the differences between the mean PAL obtained by second investigator in the first and second sessions.

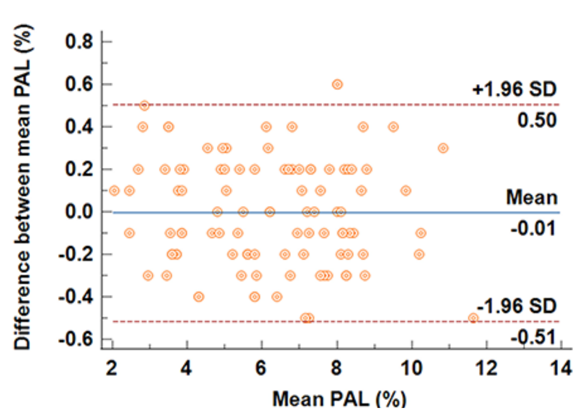


Figure 6. The Bland–Altman plot showing the differences between the mean PAL obtained by the two investigators in the first session.

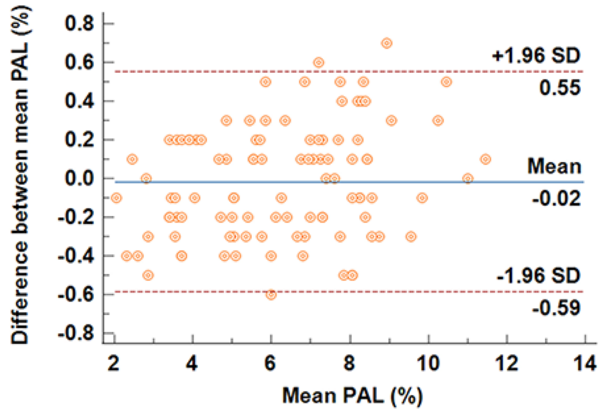


Figure 7. The Bland–Altman plot showing the differences between the mean PAL obtained by the two investigators in the second session.

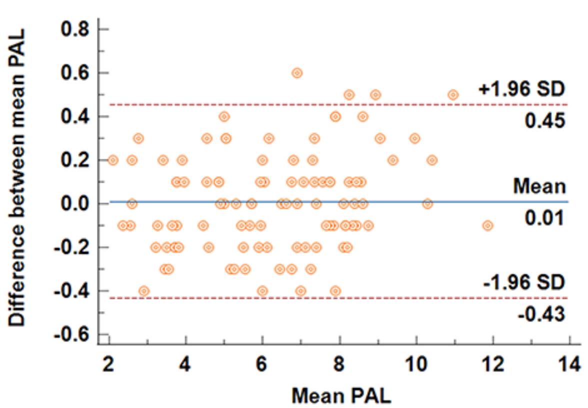


Figure 8. Correlation between the PAL estimations and Cobb angle measurements obtained by first investigator in the first session.

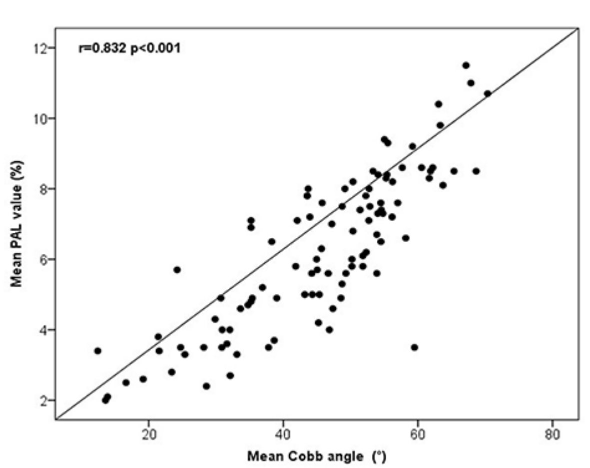


Figure 9. Correlation between the PAL estimations and Cobb angle measurements obtained by second investigator in the first session.

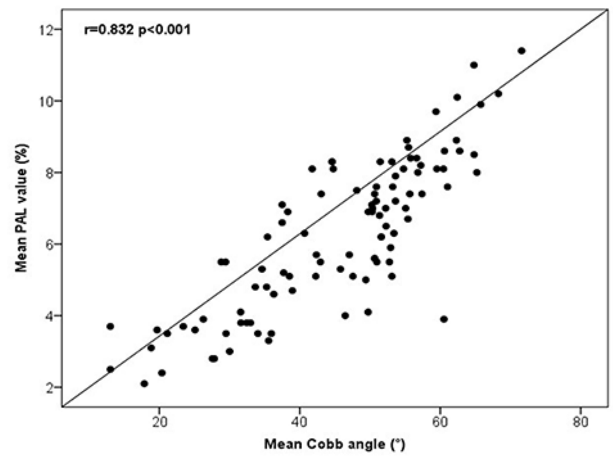


Figure 10. Correlation between the PAL estimations and Cobb angle measurements obtained by first investigator in the second session.

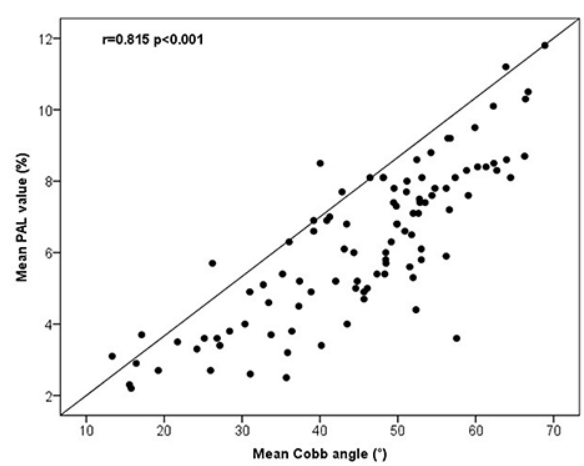
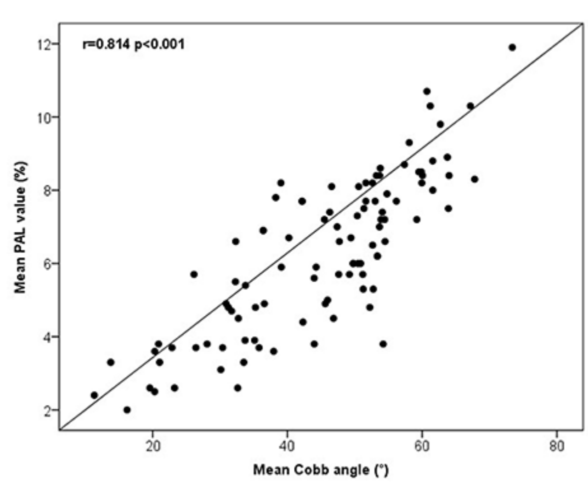


Figure 11. Correlation between the PAL estimations and Cobb angle measurements obtained Investigator 2 in the second session.



DISCUSSION

The Cobb method, originally proposed for the assessment of the severity of scoliosis, is a commonly accepted technique by clinicians for measuring the degree of lumbar lordosis (6, 7). However, it has several limitations, primarily that the Cobb angle predominantly reflects the endplate tilt of the superior and inferior end vertebrae (9). Therefore, two lumbar curvatures of different magnitudes may result in an identical Cobb angle (1, 13). Another limitation of the Cobb method is that Cobb angle measurement is influenced by irregularity in vertebral endplates (14). As the lateral projection of the vertebral end-plates is not suitable for drawing tangential lines, a variety of lines may be drawn parallel to vertebral endplates (14, 15). Thus, the value obtained in the Cobb method is affected by the pathology of the reference vertebral surface.

To date, various alternative methods have been developed for examining lumbar lordosis and these have been compared with the Cobb method (1,9). The most popular alternative methods are the Harrison Posterior Tangent Method (HTPM), the TRALL method, and the Vertebral Centroid method (15-17). In the HPTM, first described by Gore et al. (18), the angle of the lordotic curvature is defined between two straight lines, drawing tangentially to the posterior walls of the end vertebrae (16). Similar to the Cobb method, the HPTM provides a practical approach to segmental and global analysis of lumbar lordosis (5). However, like the Cobb method, the HPTM is sensitive to the irregular shape of the vertebral body. The concave-shaped posterior margin of the vertebral body affects how the straight line is drawn, resulting in different angles being measured (12). Harrison et al. (16) compared four different approaches for radiological analysis of lumbar lordosis on 30 lateral lumbar radiographs. It was reported that the HPTM results in different magnitudes of global lordosis from T12-S1 and L4-S1 than the centroid and Cobb method results (16). In the TRALL method, another tangential approach, the superior and inferior angles of the upper and lower end vertebrae are defined as points A and B, respectively. Point C is identified as the reference point with the maximal orthogonal distance from the spine to the straight lines AB. In this method, the TRALL angle is defined between straight lines AC and AB. Although the TRALL method is a reliable and reproducible method for the radiological assessment of lumbar lordosis, it is not suitable for the measurement of a substantial part of the sacrum (19). The TRALL method is not recommended as it does not allow the segmental analysis of lumbar lordosis (16). Another alternative technique based on vertebral centroid measurement of lumbar lordosis was proposed by Chen et al. (17). In the centroid method, the angle is measured between two straight lines that pass through the two vertebral centroids at both ends of the lumbar curvature. As the centroid method requires three or four vertebrae and the definition of more reference points on vertebral bodies, it is time-consuming and laborious in clinical applications (16). Centroid measurements of lumbar lordosis have been shown to be variable in specific conditions such as ankylosing spondylitis (20). Furthermore, the centroid method is not suitable for segmental analysis of L5-S1 in cases with spondylitis because the S1 vertebra is more sensitive to degenerative changes (7).

As can be seen from the literature, the suggested methods are influenced by irregularly shaped vertebral bodies and angular measurements are prone to error. The PAL approach was first described by Kuru et al. (12) in the measurement of lumbar lordosis on 24 plain radiographs. It was reported that the PAL approach could provide accurate data for evaluation of the degree of lumbar lordosis on plain radiographs. However, Kuru et al. (12) did not test the intra- and interobserver variability of the PAL method and did not compare it with the Cobb method, which is the gold standard method for measuring lumbar lordosis.

In the present study, the reliability of the PAL approach for quantifying lordotic curvature on lateral radiography was examined. The results of the study showed that the PAL approach had high intra- and interobserver reliability with all ICC values>0.929 for lumbar lordosis measurements on digital radiographs. Tangential radiographic evaluation of lumbar lordosis is influenced by irregularity in vertebral endplates and the posterior margin of the vertebral body (12, 14, 15). Degenerative changes make the vertebral endplates a less distinct landmark for the Cobb method (21). Therefore, the obtained value may be greatly influenced by the surface pathologies of the reference vertebrae. In the PAL technique, the observer can easily identify the anatomic bony landmarks on the first and fifth lumbar vertebral bodies. In contrast to tangential radiographic approaches, the estimated PAL value is not affected by the irregular shape of the vertebral body because the PAL technique is based on the manual delineation of the posterior margins of the vertebral bodies in the curvature (12, 14, 15). The PAL technique provides quantitative information independent of the vertebral endplate architecture or marginal convexity in the vertebra body (6). Thus, the PAL method may manage to assess an irregularly shaped curvature of the spine on lumbar lordosis measurement.

The main limitation of the Cobb method is that the Cobb angle is related to changes in the inclination of the end vertebrae rather than changes within the lordotic curvature. Therefore, it cannot reveal regional curvature changes (1,9). The PAL method reflects the curvature changes in the lumbar region because it is based on surface area measurements formed by the lordotic curvature. The values obtained are closely related to the magnitude of the curvature in the lumbar region. An increase in the severity of lumbar lordosis will be reflected in an increased PAL measurement. The method described in this study could overcome all the handicaps and limitations of the previous methods.

Cobb angle measurement still remains the gold standard in current clinical diagnosis when quantifying the magnitude of the lumbar curvature. Therefore, the PAL approach was compared with the Cobb method in this study. The PAL estimation results obtained by both investigators were seen to be highly correlated with the Cobb angle measurements for the assessment of the lumbar lordosis.

Limitations

A limitation of this study could be said to be that although Cobb angle cut-off values have been defined for normal or pathological degrees of measurement, cut-off values for the PAL method were not determined in this study. There is a need for further studies with a wider range of examinations to be able to determine PAL cut-off values for the clinical diagnosis of lumbar lordosis.

CONCLUSION

In conclusion, the method described here is not only simple and fast but is also a reliable technique for measuring lumbar lordosis. The PAL method provides quantitative data independent of the vertebral surface pathologies of the reference vertebrae. This method could manage to evaluate the irregularly shaped curvature in the lumbar spine. Therefore, the PAL approach could be used as an alternative and potent diagnostic criterion to determine the degree of lumbar lordosis on lateral radiographs.

Peer-review: Externally peer-reviewed.

Compliance with Ethical Standards: Ethics committee approval was received for this study from the Hitit University Clinical Researches Ethical Committee (Decision Date: 2021 Approval No:436).

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Conflict of Interest: The authors have no conflicts of interest to declare.

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