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ANALYSIS OF SPINE ALIGNMENT IN PATIENTS WITH LUMBAR POSTURAL ASYMMETRY USING PATIENT-FRIENDLY DIGITAL ANTHROPOMETRIC METHOD

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ABSTRACT

Objective: *The frequent use of intense X-rays in the diagnosis and follow-up of adolescent scoliosis patients results in radiation exposure. This study aims to explore the viability of a patient-friendly digital anthropometry method as an auxiliary tool. It also evaluates the correlation between this digital method and the Cobb method in assessing lumbar scoliosis values.*

Material and Method: *100 scoliosis patients were examined using the digital anthropometric method with 17 anatomical parameters defined. Lumbar scoliosis degrees were also measured using the Cobb method based on radiological images.*

Result: *The patients had a female to male ratio of 3:1, and 49% were diagnosed with lumbar scoliosis. The patient with the highest lumbar scoliosis displayed a 13.8 degree cervical lordosis angle, a 50.1 degree thoracic kyphosis angle, and a 26.4 degree lumbar lordosis angle. This lumbar lordosis angle was above the mean value. Conversely, the patient with the lowest lumbar scoliosis had a 12.9 degree cervical lordosis angle, a 53.81 degree thoracic kyphosis angle, and a 21.8 degree lumbar lordosis angle, with the latter being below the mean value. A significant positive correlation was observed between the lumbar lordosis angle obtained from the photo-anthropometric analysis and the lumbar scoliosis degree measured using the Cobb method (r=0.902, p<0.001).*

Conclusion: *Patient follow-up can be enhanced through the photo-anthropometric method, and due to its patient-friendly nature, it can be more integrally included in treatment programs.*

Keywords: *Lumbar vertebrae, scoliosis, data analysis, computer-assisted diagnosis, scoliosis.*

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LUMBAR POSTURAL ASİMETRİLİ HASTALARDA OMURGA DİZİLİMİNİN HASTA DOSTU DİJİTAL ANTROPOMETRİK YÖNTEM İLE ANALİZİ

ÖZET

Amaç: Ergenlik dönemi skolyoz hastalarının tanı ve takibinde yoğun X-ışını kullanılması radyasyona maruz kalma riskini artırır. Bu çalışmanın amacı, hasta dostu dijital bir antropometrik yöntemin uygulanabilirliğini araştırmaktır. Aynı zamanda bu dijital yöntemin ve Cobb yönteminin lumbar lordoz değerlerini değerlendirmedeki korelasyonunu incelemektir.

Materyal ve Metot: 100 skolyoz hastasının lumbar eğriliği, 17 anatomik parametre tanımlandıktan sonra dijital antropometrik yöntemle incelendi. Lumbar eğrilik dereceleri de radyolojik görüntülere dayanarak Cobb yöntemi ile ölçüldü.

Bulgular: Hastaların kadın erkek oranı 3:1'di ve %49'unda lumbar skolyoz tanımlandı. En yüksek lumbar skolyoza sahip olan hastanın servikal lordoz açı değeri 13,8 derece, torasik kifoz açısı 50,1 derece ve lumbar lordoz açısı 26,4 derece bulundu. Bu lumbar lordoz açısı ortalamadan yüksekti. Tersine, en düşük lumbar skolyoza sahip hastanın servikal lordoz açısı 12,9 derece, torasik kifoz açısı 53,8 derece ve lumbar lordoz açısı 21,8 derece saptandı ve bu son açı ortalamadan düşüktü. Foto-antropometrik analiz ile elde edilen lumbar lordoz açısı ve Cobb yöntemiyle ölçülen lumbar skolyoz derecesi arasında anlamlı pozitif korelasyon gözlendi ($r=0,902$, $p<0,001$).

Sonuç: Foto-antropometrik yöntem ile hasta takibi artırabilir ve hasta dostu olması nedeniyle tedavi programlarına daha fazla dahil edebilir.

Anahtar kelimeler: Lumbar vertebra, skolyoz, veri analizi, bilgisayar destekli tanı, omurga eğrilmeleri.

INTRODUCTION

Normal human posture is characterized of the vertical position, which is anchoredion spinal alignment and its orientation relative to the individual's head and pelvis.[1,2] Scoliosis is a medical condition characterized by an abnormal lateral curvature of the spine. It can appear in different forms, such as C-shaped or S-shaped curves, and its severity varies among individuals. While the exact cause of scoliosis is often unknown, it can result from genetic factors, neuromuscular conditions, or other health issues.[3-7] However, while the Cobb method is the standard practice for measurement and MRI provides detailed insights, both are expensive. Additionally, X-ray methods pose radiation risks, which necessitates heightened awareness and caution, especially in school screening and cohort studies.[3-9] The Adam's test is another commonly employed method for school screening, wherein children are assessed in a forward bending position using a scolyometer.[10,11] Even though this method is preferred because it is radiation-free, it still lacks standardization due to potential positioning errors and varying interpretations. Photo-anthropometry focuses on the projection of the center of gravity with the assistance of a force platform, while evaluating standing posture through both frontal and sagittal planes.[12-17]

In this study, we propose using distance measurements between anatomical points captured in body photographs to identify scoliosis, panel differences, and asymmetries, given that bone curvatures influence one's posture. The aim of this study is to evaluate photo-anthropometric image data (non-radioactive measurement method) in patients with lumbar scoliosis.

MATERIAL AND METHOD

Study Design

This study encompassed 100 non-operated scoliosis patients who had been receiving treatment and undergoing monitoring for at least a year at the Orthopedics and Traumatology Surgery Clinic. The sample group was formed on a voluntary basis from patients under follow-up at the orthopedic clinic. Those who had undergone surgery and those who were not willing to participate were not included in the study. Participants were randomly selected from outpatients using the complete randomization method. To safeguard against the potential adverse effects of radiation on spine development, the study exclusively included patients aged between 10 and 21 years.

Ethical Approval

Ethics approval for this study was obtained from our university's Human Research Ethics Committee (18-6.1/32, Date: 19.06.2018.). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Using the photogrammetric method, we analyzed the lumbar lordosis angles of 100 scoliosis patients after identifying 17 distinct anatomical parameters.

Furthermore, lumbar scoliosis degrees were ascertained using the Cobb method applied to radiological images (Figure 1). The mean values of the 17 anatomical parameters in all patients and in patients with lumbar scoliosis were compared. The statistical correlation between photo-anthropometric values and radiological measurements was evaluated.

Step of Preparing the Study Environment

A digital camera, a non-toxic colored marker, and a measuring tape were used for this study. The measuring tape was positioned vertically next to the patient. A Nikon D3100 digital camera was set up 280 cm away from the patient on a tripod with the camera height adjusted to 130 cm.

Preparing Patients Photo-anthropometry

Researchers employed a digital camera for capturing images, and body reference points were marked using a non-toxic colored marker.

Positioning Patients for Body Posture Evaluation

We took nine distinct photographs of each patient, capturing posterior, anterior, and lateral views while patients stood in their typical, relaxed posture (Figure 2a-d). The standardized photographic evaluation involved capturing images of spontaneous standing frontal posture. Left sagittal profiles including: Standard left side view, Actively corrected left side, Forward bending on the left side, spontaneous standing from the back. Right sagittal profiles including: Standard right side view, Actively corrected right side, Forward bending on the right side, Both front and back views during forward bending. To accurately determine the angle of trunk rotation at different levels, we captured several photographs of subjects in various forward bending positions (Figure 2,3).

Labelling Anatomical Body Points

We marked several anatomical landmarks on the body, including the sternal facet of the clavicle, acromial facet of the clavicle, inferior angle of the scapula, anterior superior iliac spine (right and left), posterior superior iliac spine (right and left), spinous processes C7, T2, T7, T12, L3, and L5 levels, the center of the greater trochanter (both right and left), and the center of the external malleolus of the ankle joint (Figures 2a-d).

Assessment of Photo-anthropometric Technique Parameters

Photo-anthropometric parameters were established to evaluate the spinal alignment of patients with scoliosis (Figure 3).

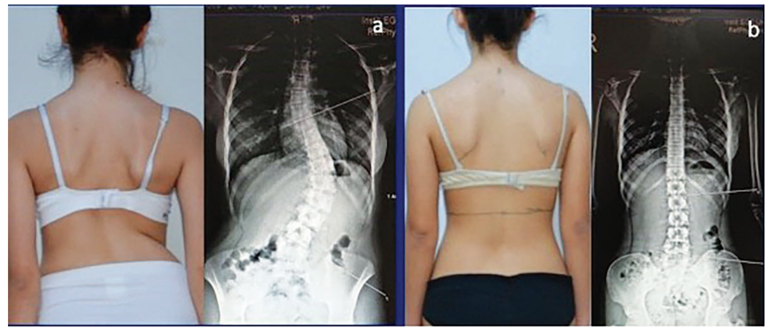

Figure 1. Photo-anthropometric and radiological comparisons of patients with lumbar scoliosis. Panel **a** illustrates the patient with the most pronounced lumbar scoliosis, while panel **b** depicts the patient with the least pronounced scoliosis.

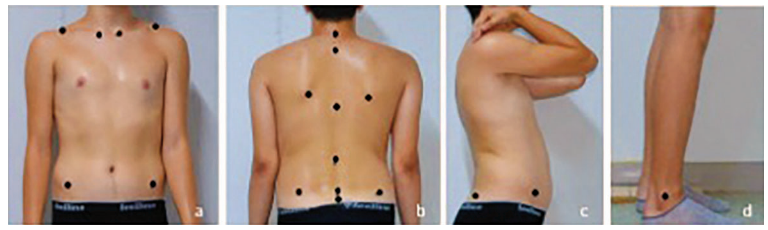

Figure 2. a-d. Depiction of anatomically marked points on the body and standard positions for the photo-anthropometric method. **a.** Sternal facet of clavicle, acromial facet of clavicle, right and left anterior superior iliac spine. **b.** Inferior angle of the scapula, right and left posterior superior iliac spine, and spinous process C7, T2, T7, T12, L3, and L5. **c.** Right and left anterior superior iliac spine, and posterior superior iliac spine. **d.** Center of external malleolus of the ankle joint.

Cervical Lordosis Angle (CLA): This angle is formed between the line connecting the external occipital protuberance and the C7 spinous process, intersecting with the horizontal line at C4. It's measured in a lateral view.

Thoracic Kyphosis Angle (TKA): In the lateral view, this angle is formed between the lines connecting the C7 and T12 spinous process, where they intersect with a horizontal line passing through T7 and the true vertical line.

Lumbar Lordosis Angle (LLA): Measured in the lateral view, this angle is between the lines T12 and L5 spinous process lines where they the horizontal line passing through L3 and the true vertical line.

Sagittal Pelvic Tilt Angle (PTA): This angle is created between the line connecting the anterior superior iliac spine and posterior superior iliac spine, compared with the horizontal line. It's measured in a lateral view.

Anterior Superior Iliac Spine Angle (SIASA): This is the angle between the line connecting the right and left anterior superior iliac spines and the horizontal line, as seen from the anterior view.

Posterior superior iliac spine angle (SIPSA): In the posterior view, this is the angle between the line connecting the right and left posterior superior iliac spines and the horizontal line.

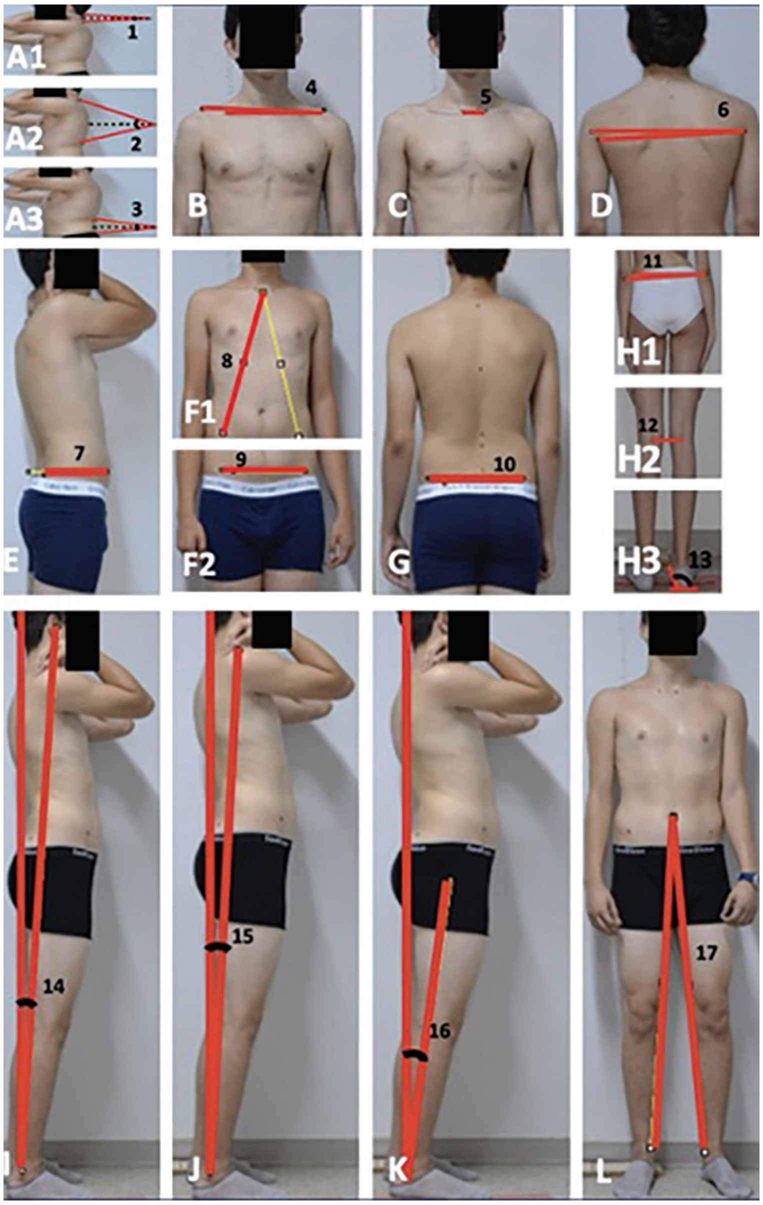

Figure 3. Digital photo-antropometric measurements detailed. **A. 1:** Cervical lordosis angle. **2:** Thoracic kyphosis angle. **3:** Lumbar lordosis angle. **B. 4:** Acromioclavicular angle. **C. 5:** Sternoclavicular angle. **D. 6:** Axilla height angle. **E. 7:** Sagittal pelvic tilt angle. **F. 8:** Distance between the jugular notch of the sternum. **9:** Anterior superior iliac spine angle. **G. 10:** Posterior superior iliac spine angle. **H. 11:** Olecranon central angle. **12:** Popliteal area center angle. **13:** Foot inclination angle. **I. 14:** Ear-ankle angle. **J. 15:** Acromion-ankle angle. **K. 16:** Greater trochanter-ankle angle. **L. 17:** Lower extremity length.

Olecranon Central Angle (OA): This is the angle between the line connecting the right and left olecranon processes and the horizontal line, measured from a posterior view.

Popliteal Area Center Angle (FPA): Measured in the posterior view, this is the angle between the line connecting the right and left popliteal areas and the horizontal line.

Ear - Ankle Angle (EAA): In the lateral view, this angle is formed by the vertical line drawn from the center of the lateral malleolus and the line connecting this center to the ear's tragus.

Acromion - Ankle Angle (AAA): This angle is formed by two lines in a lateral view: one is a vertical line drawn from the center of the lateral malleolus, and the other connects this center point to the acromial process of the scapula.

Trochanter Major - Ankle Angle (TAA): In the lateral view, this angle is formed by the vertical line drawn from the center of the lateral malleolus and the line from center of the greater trochanter.

Foot Inclination Angle (FIA): Measured in the posterior view, this angle is between the line connecting the right medial malleolus to the medial sole and the horizontal line.

Lower Extremity Length (LEL): This is the distance, in centimeters, between the anterior superior iliac spine and the lateral malleolus.

Distance Between Jugular Notch of Sternum and Right Anterior Superior Iliac Spine-(IJSSIASL): This is the distance, in centimeters, between the jugular notch of the sternum and both the right and left anterior superior iliac spines.

Acromioclavicular Angle (ACA): In the lateral view, thisis the angle between the acromion (a bony projection on the scapula or shoulder blade) and the clavicle (the collarbone).

Sternoclavicular Angle (SCA): This refers to the angle between a horizontal line and a line connecting the right and left sternal facets of the clavicle when viewed from the front.

Axilla Height Angle (AHA): This angle is formed between a horizontal line and a line drawn between the axillary regions when viewed from the back.

Measuring the Cobb Angle: A radiologist measured the Cobb angle for all patients.

Using the ImageJ Program: All images were loaded to the computer where the distance between the points and angles are measured within a standard using ImageJ software. ImageJ is an open-source Java-based image processing software available for Windows, Mac OS X, and Linux. The program allows users to view, edit, analyze, process, save, and print images in 8-bit, 16-bit, and 32-bit formats. The software can be downloaded at no cost. To use ImageJ: Open the ImageJ program. Transfer the patient's photograph into the program by selecting "Open" from the "File" menu.

In the program, create a 1 cm line on the guide ruler based on the scale present in each patient's photograph and note down the pixel value of this length. Close the guide page.

Navigate to "Set Scale" under the "Analyze" menu and input the previously noted pixel value. Measure the determined angles and lengths for each patient. These measurements were conducted by a researcher with a master's degree in anatomy. This process was repeated for each patient.

Statistical Analysis

The minimum, maximum, and average values of the angles and lengths for scoliosis patients were calculated using the Excel Program. All statistical analyses were carried out using IBM SPSS version 25.0. Paired t-tests were employed to assess differences between mean values of all patients and those with specific conditions such as lumbar scoliosis and double scoliosis. The same tests were used to evaluate differences by gender. The Wilcoxon Signed Rank test was applied to ascertain differences in measurements between the right and left sides. Lastly, a statistical correlation was determined between the lumbar lordosis angle and the degree of lumbar scoliosis.

RESULTS

Patient Demographics

The study encompassed a total of 100 scoliosis patients, comprising 26 males and 74 females, resulting in a male to female ratio of 1:3. A breakdown of the scoliosis types revealed the following distribution: Lumbar scoliosis: 49% (49 patients; 35 female, 14 male), thoracic scoliosis: 22% (22 patients; 16 female, 6 male), Double major scoliosis: 20% (20 patients; 17 female, 3 male) and thoracolumbar scoliosis 9% (9 patients; 6 female, 3 male,).

Photo-Anthropometric Measurements

Cervical lordosis angle, thoracic kyphosis angle and lumbar lordosis angle values in scoliosis patients were measured.

Cervical Lordosis Angle: The average cervical lordosis angle for all participants was to be 12.5°. In patients with the most severe lumbar scoliosis, the cervical lordosis angle was 13.8°, which was above the average. Conversely, those with the mildest lumbar scoliosis had a cervical lordosis angle of 12.9°.

Thoracic Kyphosis Angle: The average thoracic kyphosis angle among participants was 53.9°. However, for patients with the most pronounced lumbar scoliosis, the thoracic kyphosis angle was 50.1°, which is below the average. For those with the least lumbar scoliosis, the thoracic kyphosis angle was 53.81°.

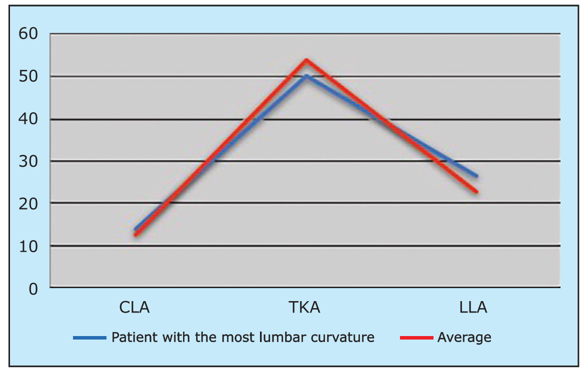

Figure 4. Comparative analysis of cervical lordosis angle (CLA), thoracic kyphosis angle (TKA), and lumbar lordosis angle (LLA) against the mean values of the patient with the most pronounced lumbar scoliosis.

Lumbar Lordosis Angle (LLA): The overall mean lumbar lordosis angle was 22.6°. For those with the highest degree of lumbar scoliosis, the lumbar lordosis angle was 26.4°, surpassing the mean. Conversely, the lumbar lordosis angle for patients with the least lumbar scoliosis was 21.8°, falling below the mean.

It's notable that patients with the highest degree of scoliosis exhibited cervical lordosis angle and lumbar lordosis angle values exceeding the average, while their thoracic kyphosis angle was below the average (Figure 4).

The values of photographic measurements in patients presenting with scoliosis is elaborated in Table 1.

A. The right ear-ankle angle and left ear-ankle angle were observed to be below the average value. In contrast, the left acromion-ankle angle and right acromion- ankle angle, left trochanter major-ankle angle - right trochanter major-ankle angle and left lower extremity length - right lower extremity exceeded the mean value.

B. The values for the anterior superior iliac spine angle, posterior superior iliac spine angle, and sagittal pelvic tilt angle below the average.

C. Both left and right-side measurements of the distance between the jugular notch of the sternum and anterior superior iliac spine were nearly identical.

D. The olecranon central angle was below the average, while the popliteal area center angle, right foot inclination angle, and left foot inclination angle were approximate to the mean.

E. The cervical lordosis angle and thoracic kyphosis angle were found to be below the average, whereas the lumbar lordosis angle was above the mean.

Table 1. Values of photo-anthropometric method parameters.

Measurements	All patients	Lumbar curvature	p-value
Cervical lordosis angle (CLA)	12.5° ± 1.3° (9.1 - 15.7)	12.2° ± 1.3 (9.1 - 15.1)	(p>0.05) lower than average
Thoracic kyphosis angle (TKA)	53.9° ± 4° (41.4 - 63.6)	51.6° ± 3.6° (41.4 - 57.7)	(p>0.05) lower than average
Lumbar lordosis angle (LLA)	22.6° ± 1.5° (20.1 - 26.4)	23.0° ± 1.3° (20.5 - 26.4)	(p>0.05) higher than average
Sagittal pelvic tilt angle (PTA)	2.4 ± 1.1° (0.9 - 7.6)	2.2 ± 0.9° (1.1 - 4.8)	(p>0.05) lower than average
Anterior superior iliac spine angle (SIASA)	1.7° ± 0.9° (0.8 - 5.3)	1.7° ± 0.8° (0.8 - 3.5)	(p>0.05) lower than average
Posterior superior iliac spine angle (SIPSA)	2.0 ± 1° (0.6 - 4.8)	2 ± 0.9° (0.9 - 4.7)	(p>0.05) lower than average
Olecranon central angle (OA)	1.91° ± 1.3° (0.4 - 6.4)	1.9° ± 1.4° (0.4 - 5.9)	(p>0.05) lower than average
Popliteal area center angle (FPA)	1.5° ± 0.7° (0.7 - 4.9)	1.5° ± 0.7° (0.7 - 3.4)	(p>0.05) close to the mean
Right ear - ankle angle (REAA)	1.7° ± 1.1° (0.1 - 5.4)	1.6° ± 1.0° (0.15 - 4.6)	(p>0.05) lower than average
Left ear - ankle angle (LEAA)	2.3° ± 1.4° (0.1 - 4.9)	2.2° ± 1.3° (0.1 - 4.4)	(p>0.05) lower than average
Right acromion - ankle angle (RAAA)	1.9° ± 0.8° (0.2 - 5.1)	1.9° ± 0.9° (0.2 - 5.1)	(p>0.05) higher than average
Left acromion - ankle angle (LAAA)	2.9° ± 1.1° (0.2 - 5.3)	3.0° ± 1.0° (0.5 - 4.8)	(p>0.05) higher than average
Right trochanter major - ankle angle (RTAA)	6.2° ± 1.5° (0.8 – 10.4)	6.3° ± 1.6° (0.8 - 10.4)	(p>0.05)
Left trochanter major - ankle angle (LTAA)	7.1° ± 1.6° (2.0 - 10.7)	7.2° ± 1.5° (2.6 - 10.7)	(p>0.05)
Right foot inclination angle (RFIA)	94.4° ± 5.9° (80.5 - 108.4)	94.7° ± 6.1° (80.5 - 108.4)	(p>0.05)
Left foot inclination angle (LFIA)	91.0° ± 5.4° (77.1 - 105.3)	90.8° ± 5.1° (80.0 - 103)	(p>0.05)
Right lower extremity length (RLEL)	73.3 ± 10.3 (39.3 - 100.8)	74.0 ± 9 cm (39.3 - 86.1)	(p>0.05)
Left lower extremity length (LLEL)	73.3 ± 10.2 (39.3 – 101)	74.1 ± 8.9 cm (39.4 – 86)	(p>0.05)
Distance between jugular notch of sternum and right anterior superior iliac spine- (RIJSSIASL)	34.2 ± 4.5 (21.6 - 50.1)	34.5 ± 4.7 cm (21.6 - 45.0)	(p>0.05) close to the mean
Distance between jugular notch of sternum and left anterior superior iliac spine (LIJSSIASL)	34.3 ± 4.2 (23.4 - 46.4)	34.8 ± 4.4 cm (23.4 - 44.5)	(p>0.05) close to the mean

Note: Values are presented as mean (SD) and (minimum to maximum). Paired t tests were used to examine any differences between all patients and lumbar curvature mean values (p<0.05).

Paired t tests were used to examine the differences of mean values between female and male in scoliosis patients (table 2).

a. Significant differences were detected in female thoracic kyphosis angle - lumbar lordosis angle values ($p<0.05$).

b. A notable variance was seen in female posterior superior iliac spine angle and anterior superior iliac spine angle values ($p<0.05$).

c. No significant difference was identified in male popliteal area center angle and olecranon central angle values ($p>0.05$).

d. Similarly, there was no significant difference observed in female measurements for both the left and right-side distances between the jugular notch of sternum and the anterior superior iliac spine values ($p>0.05$).

e. A statistically significant variance was noted observed in female left foot inclination angle compared to the right foot inclination angle values ($p<0.05$).

The thoracic kyphosis angle and lumbar lordosis angle values were both found to be higher in females compared to male patients ($p<0.05$).

Female patients also exhibited higher left foot inclination angle - right foot inclination angle values than their male counterparts ($p<0.05$).

Correlation Analysis

A robust correlation was found between the lumbar lordosis angle determined by the photo-anthropometric technique and the scoliosis degree established by the Cobb technique ($r=0.902$, $p<0.001$). These findings were consistent with measurements obtained from X-rays, reinforcing that the photo-anthropometric technique can serve as an auxiliary tool to radiological methods for diagnosis and monitoring.

DISCUSSION

Various techniques have been suggested for body posture evaluation, ranging from straightforward photographic methods and plumb line measurements to more complex tools such as goniometers, inclinometers, linear devices, and computer-assisted systems.[9,12,16,18,19] Among these, digital calculation-a non-invasive method-is increasingly favored for clinical and research assessment of the musculoskeletal system in both healthy and unhealthy individuals.[20-28]

Cobb *et al*. believe that digital photo-anthropometry is invaluable for a two-dimensional evaluation of body posture in regular clinical settings.[21] Girdler *et al*. claim that digital photo-anthropometry technique can be used for scientific assessment provided that the procedures in question are taken into account.[5] Recent studies, including those by Karimian *et al*. and Girdler *et al*., emphasize the diagnostic capabilities and scientific relevance of this method, given its objectivity, ease of use, and affordability.[5,29] According to Krawczky *et al*, the simplicity of assessing the posture through the photos is at the core of this technique - it is objective, easy to use, and of low cost.[30]

Our research heavily utilized the photo-anthropometric technique. We found that the proportion of females was notably higher in both the general scoliosis patient group (3:1) and lumbar scoliosis patients (35:14). Almost half of our study participants exhibited lumbar scoliosis.

The photo-anthropometric method is adept at assessing children's posture in various situations, including standing, sitting, and even when carrying heavy backpacks.[21,26-28,30] It enables quantification of body angles or distances, offering a detailed posture assessment based on 28 specific parameters, mainly devised for lumbar scoliosis evaluations. These parameters include various angles and distances, such as ear-ankle angle and cervical lordosis angle.[21,26-28,30] For the purpose of our study, additional anatomical points were identified, such as the sternal facet of the clavicle and spinous processes of specific vertebrae. These points were easy to mark and evaluate.

When contrasting the photo-anthropometric method with visual assessments, some inconsistencies in terms of accuracy and methodology were detected. One significant challenge was the placement of marked anatomical points, which, if misplaced, could impact the results.

Chen *et al*. introduced an approach for anthropometric analysis of thoracic kyphosis and lumbar lordosis.[13] Although their method offers insights, it doesn't match the accuracy of radiologic measurements. They proposed the calculation of the angle of lumbar lordosis, thoracic kyphosis, and cervical lordosis by using markers placed at L5, T12 and C7.[13] Degrees reported by Ferreira *et al*. are 55.4 for thoracic kyphosis and 47.7 for lumbar lordosis, compared to means reported by Grant *et al*. as 36 and 51, respectively.[19,28] In our research, the mean values for cervical lordosis, thoracic kyphosis, and lumbar lordosis angles were 12.5°, 53.9°, and 22.6°, respectively.

Table 2. Measurements of photo-anthropometric parameters segmented by gender in patients with scoliosis.

Measurements	Male patients	Female patients	*p*-value
Cervical lordosis angle (CLA)	12.8° ± 0.7° (12.1 - 14.4)	13.2° ± 0.9° (9.6 - 15.7)	($p>0.05$)
Thoracic kyphosis angle (TKA)	53.3° ± 2.8° (50.3 – 59.8)	56.5° ± 3.9° (41.4 – 63.6)	*($p<0.05$)
Lumbar lordosis angle (LLA)	20.7° ± 1.4° (19.6 – 25.1)	23° ± 1.1° (20.5 - 26.4)	*($p<0.05$)
Sagittal pelvic tilt angle (PTA)	2.2 ± 1° (1.4 – 4.8)	2.2 ± 1.1° (1 – 7.6)	($p>0.05$)
Anterior superior iliac spine angle (SIASA)	1.5° ± 0.7° (0.8 – 3.1)	1.8° ± 1° (0.8 – 5.3)	*($p<0.05$)
Posterior superior iliac spine angle (SIPSA)	1.6 ± 0.8° (1 – 3.6)	1.9 ± 0.9° (0.6 - 4.6)	*($p<0.05$)
Olecranon central angle (OA)	1.82° ± 1.1° (0.5 – 3.8)	2.1° ± 1.5° (0.4 – 6.4)	($p>0.05$)
Popliteal area center angle (FPA)	1.5° ± 0.5° (0.9 – 2.8)	1.5° ± 0.7° (0.7 – 4.9)	($p>0.05$)
Acromioclavicular angle (ACA)	2.2° ± 1.5° (0.6 – 4.8)	2.5° ± 1.6° (0.4 - 7.2)	($p>0.05$)
Sternoclavicular angle (SCA)	2° ± 1.3° (0.5 – 4.8)	2.4 ± 1.4° (0.2 - 7)	($p>0.05$)
Axilla height angle (AHA)	2° ± 1.4° (0.6 – 6.2)	2.4° ± 1.7° (0.6 – 9.4)	($p>0.05$)
Right foot inclination angle (RFIA)	93.3° ± 6.7° (80.5 – 105)	94.1° ± 6.1° (82.2 – 108.4)	*($p<0.05$)
Left foot inclination angle (LFIA)	88.4° ± 5.4° (78.1-98.4)	91.7° ± 5.4° (81-105)	*($p<0.05$)
Distance between jugular notch of sternum and right anterior superior iliac spine- (RIJSSIASL)	33.7 ± 2.9 cm (30 – 40.5)	34.2 ± 4.6 cm (24.2 - 51)	($p>0.05$)
Distance between jugular notch of sternum and left anterior superior iliac spine (LIJSSIASL)	34 ± 2.9 cm (30 – 40.5)	35.2 ± 4.3 cm (24.6 – 46.43)	($p>0.05$)

Note: Values are presented as mean (SD) and (maximum to minimum). Paired t tests then were used to examine any differences between female and male mean values. ***:** Results showed significant differences between female and male mean values ($p<0.05$).

In a study by Ruivo *et al*., the photo-anthropometric method was employed to evaluate the posture of 275 healthy students aged between 15 and 17.[31] The mean value of sagittal head angle was 17.2°±5.7°, cervical angle was 47.4°±5.2°, and shoulder angle was 51.4°±8.5°. Sagittal head and cervical angle values were higher in males than females. Forward head posture and shoulder protraction were defined as common postural disorders.[31-33] In our research, we focused on the cervical lordosis angles of scoliosis patients and found no significant gender differences.

However, significant gender-based differences were observed in thoracic and lumbar lordosis angles. Female patients typically exhibited higher values than males.

Matamalas *et al*.'s study assessed 80 idiopathic scoliosis patients, evaluating shoulder elevation angle, axilla height angle, and trapezius muscle angle using the photogrammetric method.[34] Compared to their results, our study found a higher axilla height angle.

In a study by Canhadas *et al*., 30 asthmatic children and 30 non-asthmatic children were evaluated for body posture. The knee flexion angle of asthmatic individuals was significantly lower than that of the control group. While angles such as acromioclavicular, sternoclavicular, anterior superior iliac spine, and posterior superior iliac spine were measured for body symmetry, no significant differences were observed between the two groups. However, gender-based differences were evident in the acromioclavicular angle values among asthmatic patients.[35] In our research on scoliosis patients, no gender differences were noted in the acromioclavicular angle. Nevertheless, angles like the anterior superior iliac spine, posterior superior iliac spine, and foot inclination showed that male patients had significantly lower values than females.

Several studies have noted a positive correlation between radiographic and photo-anthropometric me asurements.[1,4,5,7,13,15,16,19] Our research also confirmed this positive association. The aim of this study was to demonstrate that detailed measurements can be made using the photo-anthropometry method. Thus, children with scoliosis can be called in for more frequent checks and can be assessed without radiation exposure. The photogrammetry method can be used to better monitor the benefits of physical exercise and brace use within the treatment given to young people. Measurements can be easily stored and repeated.

Photo-anthropometry offers distinct advantages over traditional measurement techniques. One primary advantage is its adaptability. Images and measurements can be stored, re-measured, supplemented with new parameters, and edited without issue. Ensuring correct posture is vital for accurate photo-anthropometric evaluations, which is why we emphasized patient preparation and positioning. Trained medical staff can easily execute this procedure. Proper positioning allows for concurrent photo-taking and measurements by various individuals, minimizing individual errors and ensuring reliability.

Another advantage of photo-anthropometry is the strategic and controlled analysis of lumbar posture symmetry. Furthermore, treatment outcomes are enhanced with improved patient statistics, reduced in-office time, cost-effectiveness, and streamlined patient monitoring. The cost-effective nature of producing and storing digital photos further amplifies the technology's appeal. Specialized equipment or software isn't essential, though a tripod can be invaluable for stabilizing the camera.

A limitation of our study is the patient count, suggesting future research could benefit from a larger sample size.

The non-invasiveness of photo-anthropometry makes it a valuable tool for both scientific and clinical research. This method addresses parental concerns related to the radiation risks of radiography, especially when evaluating children. Emphasizing radiation-free techniques is crucial to prevent potential harm to healthy tissues. However, this technique does have constraints, like its inability to measure trunk rotation due to its two-dimensional nature and its applicability only to patients over 7 years of age.

CONCLUSION

The routine use of radiography, given its inherent radiation risks, can adversely influence patient treatment and monitoring. Photo-anthropometric parameters present a viable auxiliary tool for assessing scoliosis patients, especially those with lumbar scoliosis.

A significant correlation exists between the female gender and scoliosis patients exhibiting lumbar scoliosis, as well as those with double scoliosis. It is particularly important to assess values like thoracic kyphosis, lumbar lordosis, anterior superior iliac spine, posterior superior iliac spine, and foot inclination angles in female patients.

In our research, patients with lumbar scoliosis displayed lumbar lordosis and acromion-ankle angle values higher than average. Conversely, values for cervical lordosis, thoracic kyphosis, sagittal pelvic tilt, anterior superior iliac spine, posterior superior iliac spine, olecranon central, and ear-ankle angles were observed to be lower. These metrics can be pivotal in the routine monitoring of scoliosis patients with lumbar scoliosis. Therefore, the photo-anthropometric method stands as a potential tool to conventional radiological methods in scoliosis evaluation.

We advocate for the patient-friendly approach of digital photo-anthropometry, foreseeing its positive impact on patient monitoring. By integrating this method, there's potential not only to enhance patient care but also to optimize resources, potentially resulting in economic savings at both individual and national levels.

The importance of photo-anthropometric analysis in patients with scoliosis is multifaceted:

1. **Accuracy and Reliability:** Photo-anthropometric methods are utilized for the precise determination of the degree and pattern of spinal curvature in scoliosis. This approach can supplement or, in some cases, substitute physical examination and traditional radiographic measurements. Photographs provide detailed visualization of spinal curvature and body posture, facilitating more accurate assessments.
2. **Non-invasive and Safe:** Contrasting with methods that require radiation exposure, photo-anthropometric analysis is non-invasive and offers assessment of spinal posture without subjecting patients to radiation. This is particularly significant for young patients and in scenarios necessitating long-term follow-up.
3. **Monitoring and Evaluation:** During the treatment process for scoliosis, photo-anthropometric methods are employed to track changes in posture and spinal curvature. This is crucial for evaluating the effectiveness of treatment and for making necessary adjustments to the treatment plan.
4. **Personalized Treatment Planning:** Photo-anthropometric analysis aids in developing customized treatment plans based on the severity and type of scoliosis. Each case of scoliosis is unique, and this method plays a vital role in determining appropriate treatment approaches for each patient's specific condition.
5. **Education and Awareness:** The method facilitates visual comprehension of the effects of scoliosis and the treatment process for patients and their families. This enhances patients' understanding of their condition and encourages more active participation in their treatment plans.

Hence, photo-anthropometric examination is an auxiliary tool in the assessment and monitoring of patients with scoliosis.

*The authors declare that there are no conflicts of interest.

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