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Research Article | Araştırma Makalesi

EVALUATION OF THE SACRAL AND COCCYGEAL CURVATURES CALCULATED VIA COMPUTED TOMOGRAPHY IMAGES BASED ON GENDER

BİLGİSAYARLI TOMOGRAFİ GÖRÜNTÜLERİ ÜZERİNDEN HESAPLANAN OS SACRUM VE OS COCCYGİS EĞRİLİKLERİNİN CİNSİYETE GÖRE DEĞERLENDİRİLMESİ

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ABSTRACT

Objective: The skeletal structure has a significant role in the estimation of human gender. The os sacrum and os coccyx bones that constitute the pelvic skeleton are important in sex estimation due to their functional differences based on sex. In the present study, we aimed to determine the differences in os sacral and os coccygeal curvatures calculated with orthogonal plane computed tomography images based on gender.

Methods: Computed tomography images of 150 healthy individuals (75 females, 75 males) between the ages of 25-50 were used in the study. The computed tomography images were edited into a suitable format by the Horos software for measurement. Six sacral and coccygeal measurements, lumbosacral angle (LSA), sacral curvature (SC), sacral kyphosis (SK), sacrococcygeal angle (SCA), sacrococcygeal joint angle (SCJA), and coccygeal curvature (CC) were conducted on the sagittal image.

Results: The measurement results indicated that LSA and SCA values were higher in male subjects when compared to females, and SCJA values were higher in females when compared to males ($p \leq 0.05$). Quadratic Discriminant Analysis (QDA) results indicated that these parameters were 93.3% effective in estimating male gender, 85.3% effective in estimating female gender, with an overall estimation rate of 89.3%.

Conclusion: According to these results, it was concluded that the lumbosacral and sacrococcygeal joints appear flatter in men than in women. SC, SK and CC parameters did not show sexual dimorphism. Considering all the parameters we used, we achieved a high rate of gender discrimination.

Keywords: Computed tomography, gender prediction, discriminant analysis, coccyx, sacrum

ÖZ

Amaç: İnsanlarda cinsiyetin belirlenmesinde iskelet yapısı anahtar bir rol oynar. Pelvis iskeletini oluşturan os sacrum ve os coccygis, cinsiyete bağlı fonksiyonel farklılıklar nedeniyle cinsiyet tayini için önemli kemiklerdir. Bu çalışmada; ortogonal düzleme getirilmiş Bilgisayarlı Tomografi (BT) görüntüleri üzerinden hesaplanan os sacrum ve os coccygis eğriliklerinin cinsiyete göre farklılıklarını belirlemeyi amaçladık.

Yöntem: Çalışmada 25-50 yaş arası sağlıklı 150 bireye ait (75 Kadın, 75 Erkek) BT görüntüleri kullanıldı. Horos yazılımı ile BT görüntüleri ölçüm için uygun formatta düzenlendi. Sagittal görüntü üzerinde; os sacrum ve os coccygis üzerinden lumbosakral açı (LSA), sakral eğrilik (SE), sakral kifoz (SK), sakrokoksigeal açı (SKA), sakrokoksigeal eklem açısı (SKEA) ve koksigeal eğrilik (KE) olmak üzere 6 farklı ölçüm yapıldı.

Bulgular: Ölçüm sonuçlarına göre; LSA ve SKA değerleri, erkeklerde kadınlara göre yüksek, SKEA değeri de kadınlarda erkeklere göre yüksek olduğu tespit edildi ($p \leq 0,05$). QDA'ya göre tüm parametrelerden erkek bireyleri ayırt etme gücü %93,3, kadın bireyleri ayırt etme gücü %85,3 ve toplam ayırt etme gücü %89,3 bulundu.

Sonuç: Bu sonuçlara göre erkeklerde lumbosakral ve sakrokoksigeal eklemlerin kadınlara göre daha düz göründüğü sonucuna varıldı. SC, SK ve CC parametreleri cinsel dimorfizm göstermedi. Kullandığımız tüm parametreler dikkate alındığında yüksek oranda cinsiyet ayrımcılığı elde ettik.

Anahtar Kelimeler: Bilgisayarlı tomografi, cinsiyet tahmini, discriminant analizi, os coccygis, os sacrum

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Introduction

It is necessary to know the ancestors, gender, age, and height of a human to define his/her biological identity in forensics and archeology.[1,2] However, major incidents such as air crashes, traffic accidents, and fire disasters might lead to problems in estimating the personal characteristics of individuals and their identities. Therefore, accuracy in sex estimation becomes highly significant in forensic and archaeological studies.[3] The pelvis and cranium bones, which were acknowledged as distinct dimorphic regions among other skeletal segments, can be widely used in sex estimation.[4,5] A plethora of studies was conducted on sex estimation based on almost all bones of the human skeleton and the accuracy of sex estimation was investigated across different populations.[6] Several studies reported that accuracy of sex estimation was 98% in skeletons with coxae and ossa cranii preserved together, 95% in skeletons with os coxae preserved alone, 90% in skeletons with ossa cranii preserved alone, and 80 to 90% in skeletons with both upper and lower extremity long bones preserved together.[7-10] The findings indicated that accurate results can be achieved even in cases where sex estimation is based only on certain bones of the skeleton. Methods such as DNA analysis, morphological, metric, geometric, morphometric, and probabilistic determination are used in sex estimation.[11] The highest accuracy is achieved via DNA analysis. However, it is still a technology that is difficult to access for developing and underdeveloped countries.[12,13] It is less complicated to evaluate and interpret the available numerical data using metric methods. Metric measurements obtained from Computed Tomography (CT) images can be used for reconstructive identification, comparative bone, and lesion identification.[14,15] CT is currently preferred as an effective method for sex estimation due to its sensitivity and due to being a low-cost, non-invasive, rapid, and reconstructive method.[11,16] It allows the researchers to re-orientate an image and constitutes new image series in different planes.

In the estimation of gender, the focus was primarily on the pelvis, which most evidently exhibited the difference between the genders, and the skull, where the size and morphological diversity were best represented.[17] The literature review revealed that the pelvis was a dimorphic region. It has been shown that the pelvis is the most reliable bone for sex determination.[4,18] The os sacrum and os coccyx in the pelvis are significant bones for gender estimation due to their functional differences.[19] The present study aims to estimate gender differences based on the sacrum and coccyx curvatures of healthy male and female individuals, calculated via the CT images, which were brought to the orthogonal plane.

Methods

The present study was approved by the Non-Interventional Clinical Research Ethics Committee, with decision number 6/3, on September 25th, 2019.

The CT images of individuals, aged between 25 and 50 years old, who were admitted to the Training and Research Hospital University, between January 2018 and June 2019 were reviewed. CT images of 110 female and 90 male subjects were randomly selected from the archive system, the Picture Archiving and Communication System (PACS). The subjects with significant degenerative diseases, bone pathologies, and history of surgery were not included in the study. As a result, CT images of 150 subjects, 75 females and 75 males, were selected for the present study.

All images were obtained using a 16-slice MDCT scanner (Aquilion 16; Toshiba Medical Systems, Tokyo, Japan) device. CT images with a slice thickness of 3 mm were obtained in the axial plane while the patients were in the supine position.

Computed Tomography

Computed Tomography is an imaging method that can show all tissues, especially bone tissues, with sharp boundaries. CT provides a three-dimensional view of the human skeleton with high bone resolution. CT allows us to measure virtual bones instead of dry bones. Since digital data is kept electronically in CT, it allows us to observe the images in detail anytime and anywhere, and to make accurate and reliable metric analysis. In addition, being re-measured and reinterpreted in data transfer between researchers increases estimation and reliability. Orientation are minor differences that may result from an individual's position on the CT device. Due to these position differences, some measurement errors due to orientation may occur during image analysis. These small errors can affect the measurement values. Therefore, in our study, all images were brought to the orthogonal plane to minimize measurement errors. In this way, it is possible to calculate the measured angles in a way that is less affected by the orientation.

Image Analysis

CT images in the PACS archive were saved in Digital Imaging and Communications in Medicine (DICOM) format and were transferred to Horos (Version 3.3, USA) personal workstation. Sagittal, transverse, and coronal image series were generated using the 3D Multiplanar Reconstruction (MPR) tool. The obtained images were brought to the standard bone dose. The images, focusing on the sacrum and the coccyx, with standard magnification, were adjusted orthogonally in three planes.

In obtaining the sagittal, transverse, and coronal image series, the sagittal images were aligned along the promontorium as the mid-axis, coronal images were aligned along the corpus vertebrae as the mid-axis, and the transverse images were aligned both along the processus spinosus of the vertebrae and the symphysis pubis. Hence, all CT image series focusing on the sacrum with standard magnification were adjusted orthogonally in three planes (Figure 1).

The length and angle tools on the Horos Software were used to conduct measurements on the sagittal image series. The measurements for each of the six parameters were conducted at 3 separate times by the same researcher, to calculate the intra-observer reliability coefficient. 6 different curvature measurements were completed on the sagittal plane based on the parameter descriptions provided in Table 1: 1. Lumbosacral Angle (LSA), 2. Sacral Curvature (SC), 3. Sacral Kyphosis (SK), 4. Sacrococcygeal Angle (SCA), 5. Sacrococcygeal Joint Angle (SCJA), 6. Coccygeal Curvature (CC) (Figure 2).

Table 1. Sagittal plane measurement

Parameters	Details
Lumbosacral Angle (LSA)	The obtuse angle between the line that joins the midpoints of the upper and lower borders of the 5th lumbar vertebra and the line that joins the midpoints of the upper and lower borders of the 1st sacral vertebra
Sacral Curvature (SC)	The acute angle between the line that joins the midpoints of the upper and lower borders of the 1st sacral vertebra and the line that joins the midpoints of the upper and lower borders of the 5th sacral vertebra
Sacral Kyphosis (SK)	The acute angle between the line that joins the midpoints of the upper and lower borders of the 1st sacral vertebra and the line that joins the midpoints of the lower borders of the 2nd and 4th sacral vertebrae
Sacrococcygeal Angle (SCA)	The obtuse angle between the line that extends from the promontorium to the sacrococcygeal joint and the line that extends from the end of the last coccyx to the sacrococcygeal joint
Sacrococcygeal Joint Angle (SCJA)	The acute angle between the line that joins the midpoints of the upper and lower borders of the 5th sacral vertebra and the line that joins the midpoints of the upper and lower borders of the 1st coccygeal vertebra
Coccygeal Curvature (CC)	The acute angle between the line that joins the midpoints of the upper and lower borders of the 1st coccygeal vertebra and the line that joins the midpoints of the upper and lower borders of the last coccygeal vertebra

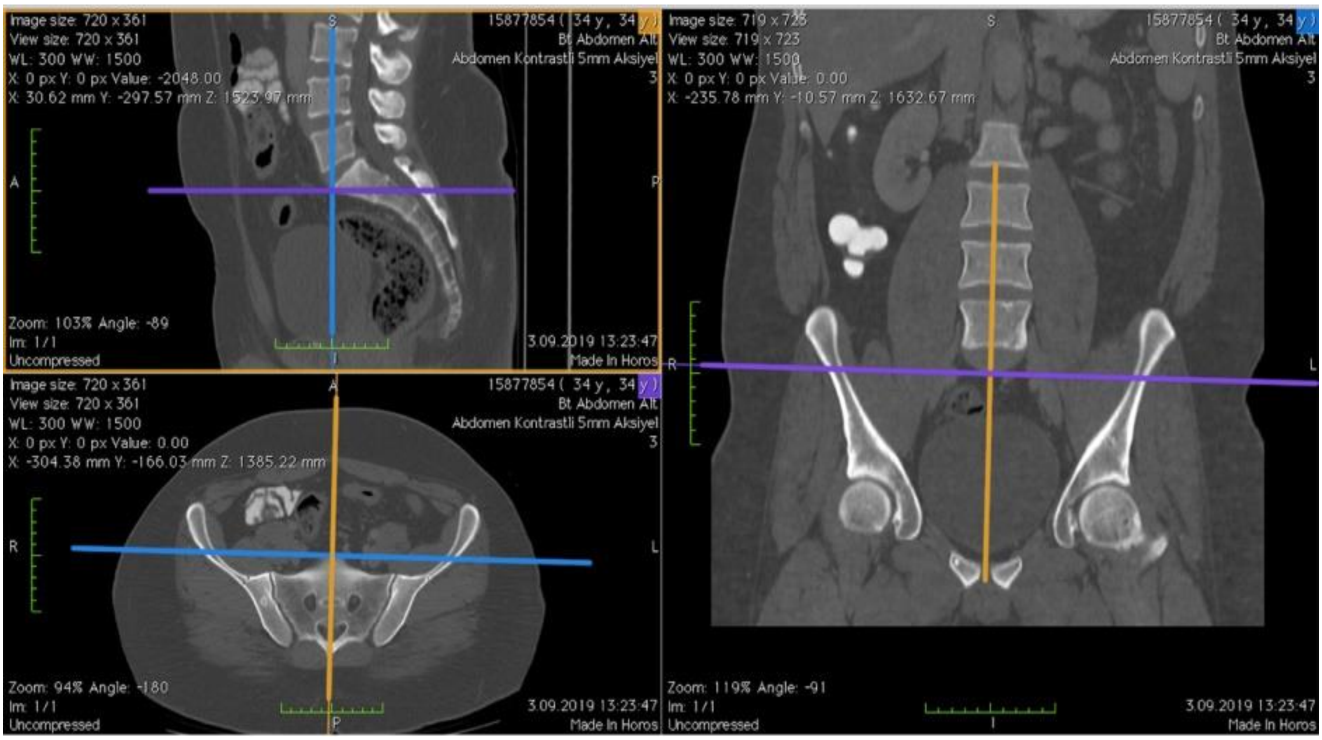

Figure 1. CT Images on the 3D Orthogonal Plane in Horos Software

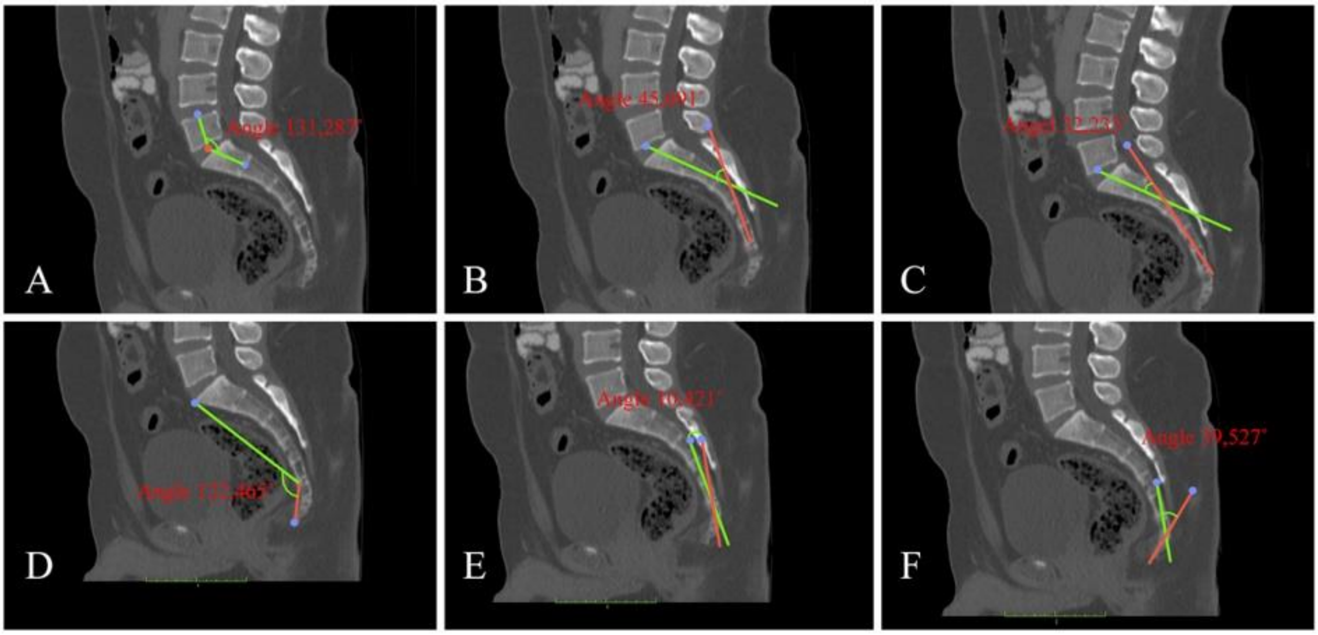

Figure 2. A: Measurement of Lumbosacral Angle, B: Measurement of Sacral Curvature, C: Measurement of Sacral Kyphosis, D: Measurement of Sacrococcygeal Angle, E: Measurement of Sacrococcygeal Joint Angle, F: Measurement of Coccygeal Curvature

Statistical Analysis

Descriptive analyses were conducted to obtain information on the characteristics of the study groups. Normality was tested with the Anderson-Darling test, which was applied for each data set. Two Sample t-test was used to study the relationship between the normally distributed data for the male and female subjects, and the Mann-Whitney U test was used to analyze the data that did not exhibit normal distribution ($p \leq 0.05$). Quadratic Discriminant Analysis (QDA) was used to analyze sex estimation. Minitab 17 software was used for the QDA analysis.

Reliability

Intraclass correlation coefficient (ICC) was used to calculate intra-observer reliability. Reliability value ranges between 0 and 1, with values closer to 1 representing stronger reliability.[20] In this study, the ICC value for intra-observer reliability was found as 0.98 for all quantitative measures. Such ICC value indicated high reproducibility.

Results

The mean ages of the 75 female and 75 male subjects, who were included in the study, were 39.2±7.2 and 40.8±6.2, respectively ($p > 0.05$).

The obtained data sets were tested for normality with the Anderson-Darling test and it was concluded that the data were not normally distributed. The Mann-Whitney U test results revealed a statistically significant difference between genders based on the parameters, LSA, SCA, and SCJA ($p \leq 0.05$). It was found that LSA and SCA measurements were higher in male subjects when compared to those of female subjects. As a result of LSA measurements, it was found that the os sacrum is located more posteriorly in women than in men compared to the 5th lumbar vertebra. With the decrease in SCA value measured between os sacrum and os coccygis, os sacrum and os coccygis are positioned more backwards. Therefore, as a result of SCA measurements, it was found that the os sacrum and os coccygis were located behind in women and more in front in men. The SCJA values were larger in female subjects when compared to male subjects. Accordingly, it was found that the position of the os coccygis relative to the 5th sacral vertebra was lower in women than in men. There was no statistically significant difference between genders based on the parameters SC, SK, and CC ($p > 0.05$) (Table 2).

Table 2. The comparison of the mean values of the parameters that did not exhibit normal distribution

	Female Median° (Min-Max)	**Male Median° (Min-Max)**	**P**
LSA	131.76 (114.17-152.52)	133.69 (118.31-156.54)	**≤0.05**
SC	50.95 (24.70-83.33)	51.08 (20.91-81.78)	0.37
SK	26.15 (9.96-53.55)	28.20 (10.42-60.90)	0.14
SCA	105.15 (73.75-143.59)	110.13 (85.54-142.29)	**≤0.05**
SCJA	17.16 (4.11-52.39)	11.19 (1.93-57.34)	**≤0.05**
CC	45.36 (2.49-94.90)	43.04 (10.78-86.88)	0.12

LSA: Lumbosacral Angle, SC: Sacral Curvature, SK: Sacral Kyphosis, SCA: Sacrococcygeal Angle, SCJA: Sacrococcygeal Joint Angle, CC: Coccygeal Curvature

In the QDA performed with six different parameters, when the average of all values in terms of gender is examined; in all parameters, the power to distinguish male individuals was 93.3%, the power to distinguish female individuals was 85.3%, and the total discrimination power was 89.3%. In other words, the adopted method in the present study was accurate in the sex estimation of 70 out of 75 male subjects and 64 out of 75 female subjects.

Discussion

As a hypothesis, in this study, we planned to reveal the differences between the sexes of the sacrum and coccyx curvatures, which are included in the pelvis skeleton, and it was determined that these bones showed dimorphism with a high accuracy rate. Studies investigating the morphometric measurements of the os sacrum in literature were commonly performed using dry bone, direct radiography, and CT methods.[15,21-23] In the literature, there is rare information about whether the images are brought to the orthogonal plane in studies using direct radiography and CT methods. In this study, the measurement technique used by Oner et al. and Turan et al.[24,25] were used. Measurements were made on CT images brought to the orthogonal plane so that the images were not affected by the orientation. However, it should be kept in mind that although CT provides multiparametric and realistic data in osteometric measurements, the sagittal measurements we use in particular can be used in centers working with post-mortem imaging.

A plethora of studies in literature conducted lumbosacral angle (LSA) measurements using the Ferguson Technique. In this technique, the acute angle between the line drawn along the upper-end plane of the sacral base and the horizontal line along the corpus of the 1st sacral vertebra is measured.[26-29] Okpala et al.[30] conducted radiological studies using the Ferguson Technique on 274 and Oyakhire et al.[27] on 220 black subjects and reported that the LSA value did not have a significant difference between the genders. The findings of the present study indicated that the LSA value was higher in male subjects compared to that of female subjects. It is the backward position of the sacrum relative to the 5th lumbar vertebra in the LSA measurement. Accordingly, as the LSA value decreases, the sacrum is positioned more backwards than the 5th lumbar vertebra. For this reason, the sacrum of women is located further back than men. Such finding is dissimilar to the findings in the literature and the dissimilarity is based on the difference in measurement methods, body position, gender, race, and working conditions, which affect LSA values. Our study revealed that LSA is one of the parameters that can be used to differentiate gender. In addition, LSA is the angle that gives normal lordosis to the waist. When examined clinically, it is thought that the decrease in LSA value affects the flattening of the lumbar lordosis in individuals. According to, low or high angulation of LSA is likely to be associated with low back pain.

Trinh et al.[31] conducted a radiological study on 40 subjects and obtained sacral curvature (SC) measurements based on the angle between the lines passing through the 1st and 5th sacral vertebrae in the sagittal plane and the lateral edges of the corpus. Trinh suggested that it was not possible to estimate gender between the males and females based on the SC measurements. However, the corpus of a vertebra increases from top to bottom. Therefore, the margin of error in the measurement increases. Woon et al.[32] conducted a retrospective study with 112 subjects and adopted a similar measurement approach with the present study, using pelvis CT images. Their findings indicated that there was no significant difference between the genders in SC value. Such findings were parallel with the data obtained in our study.

Wang et al.[26] conducted a study with 120 subjects and reported that measuring the kyphotic deformity in the sacral segment by the Cobb method was more effective in defining the sacral kyphosis (SK) value. Erbek[33] adopted the same method and established that SK values in healthy subjects did not exhibit a significant difference based on gender. We determined no statistically significant difference for the SK values in the present study.

Yoon et al.[34] conducted a study with 606 subjects and found that there were no significant differences in sacrococcygeal angle (SCA) values based on gender. In their study, they measured the SCA as the angle between a line from the midpoint of the S1 superior endplate to the midpoint of the S5 inferior endplate and a line from the midpoint of the S5 inferior endplate to the tip of the last coccygeal segment. Unlike other studies, we based the promontory in the measurement of SCA. Because we think that this measurement is more practical and can be adapted to dry bone measurements. In our study, os sacrum and os coccygis are positioned more backwards with the decrease in SCA value measured between os sacrum and os coccygis. Therefore, it was found that os sacrum and os coccygis are located more backwards in women and more anteriorly in men. Such finding indicated that SCA was a significant parameter in the estimation of gender. When examined clinically, we can emphasize that the SCA value is especially important in women in terms of delivery. We think that the data obtained as a result of the study will contribute to basic and clinical research on os sacrum in the future.

Woon et al.[32] conducted a study with 112 European subjects and stated that the sacrococcygeal joint angle (SCJA) values did not have a significant difference based on gender. In the study of Marwan et al.[35] with 202 Arab adults, they reported that os coccygis had a more ventral angle in women based on morphometric measurements. Also, the fact that men have longer and straighter coccyges and sacrums than women indicates a possible higher risk of coccidinia in women. In our study, when the SCJA value was examined, it was found that it was wider in female individuals than in male individuals.

Accordingly, the position of the os coccygis relative to the 5th sacral vertebra was found to be more dorsally in women than in men. Thus, the present study showed that the SCJA value is a significant parameter in estimating gender, despite the other findings in the literature. We argue that such difference might be due to population and environmental differences.
Kim and Suk[36] stated that the intercoccygeal angle is a useful radiological measurement in accurately assessing the increasing angular deformity of the coccyx. The coccygeal curvature (CC) value in the present study was named as the intercoccygeal angle in the literature. Kim and Suk[36] examined the CC values from the radiography of 20 Korean adult subjects and were not able to comment on sexual dimorphism due to insufficient data. Another larger CT study evaluated the CC values of 92 subjects, and it was reported that os coccyx tended to be slightly flatter in females.[37] However, the present study established no significant difference in CC values based on gender. However, the increased intercoccygeal angle can be considered as a possible cause of idiopathic coccygodynia. Insufficient sample size of the present study, different population and environmental factors might yield different findings.
A comparison of the findings in our study and the findings in the literature revealed differences in metric values and statistical results. We argue that such differences stem from the differences in measurement, racial diversities, genetic and socioeconomic differences. Furthermore, the present study conducted measurements by bringing the CT images to the orthogonal plane to minimize the margin of error and to obtain more reliable results. Hence, such an approach is the most significant factor that differentiates our study from other studies. In three-dimensional structures, the angle value differs based on the plane. Our study presents a different approach than other studies in literature, through bringing the images to the orthogonal plane and enabling more reliable measurements.

Conclusion

The measurements conducted on the os sacrum and os coccyx curvatures revealed that the LSA and SCA values were higher in male subjects when compared to female subjects, and the SCJA value was higher in females when compared to males. According to these results, it can be said that the lumbosacral and sacrococcygeal joints appear flatter in men than in women. SC, SK and CC parameters did not show sexual dimorphism. The QDA, which was performed with six different parameters, showed 93.3% discrimination power for males, 85.3% for females and 89.3% for total discrimination power. Although this article provides measurements that reveal the sex differences of the sacrum and coccyx, it may contribute to the units working with post-mortem imaging in terms of the method used.

Compliance with Ethical Standards
Our study was evaluated by Karabuk University Non-Interventional Clinical Research Ethics Committee and approval was obtained with the decision number 6/3 dated 25.09.2019.

Conflict of Interest
The authors declare no conflicts of interest.

Author Contribution
MNO: Project development, data collection, manuscript writing; ZO: Manuscript writing and editing; MN: Manuscript writing and editing; SO: Manuscript writing and data analysis

Financial Disclosure
None.

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