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Three-Dimensional Morphometric and Angular Analysis of the Human Sacrum: Implications for Sex Estimation and Clinical Application via Multidetector CT

Análisis Morfométrico y Angular Tridimensional del Sacro Humano: Implicaciones para la Estimación del Sexo y su Aplicación Clínica Mediante TC Multidetector

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SUMMARY: Understanding the morphometric and angular characteristics of the sacrum is critical not only for clinical and surgical interventions but also for reliable sex estimation in forensic and anthropological settings. Despite its importance, comprehensive analyses integrating both linear and angular measurements from high-resolution imaging remain limited. This study aims to evaluate 22 anthropometric and angular parameters of the human sacrum in relation to sex and age, using three-dimensional reconstructions obtained from multidetector computed tomography (MDCT) images. Radiological images from 100 women and 100 men, aged 18 to 91, were retrospectively analyzed. The images were obtained using Multidetector Computed Tomography and converted into three-dimensional models via Radiant Dicom Viewer software. Fourteen angular and length measurements were made on the sacrum, and statistical analysis was conducted using SPSS. Sex showed a significant effect on sacral height, width, sagittal diameter of the sacral base, lumbosacral angle, sacral kyphosis, and sacrococcygeal angle ($p < 0.05$). Some parameters demonstrated age-dependent changes, notably a decrease in sacrococcygeal angle and transverse diameter with age. This study provides a comprehensive set of morphometric reference data for the sacrum, combining linear and angular metrics in a 3D imaging context. The findings underline the relevance of specific sacral parameters in sex estimation and support their clinical value in preoperative planning and spinal instrumentation.

KEY WORDS: Sacrum; Coccyx; Computed Tomography; Sex determination.

INTRODUCTION

Anthropometric and angular measurements of the sacrum are currently used in many fields such as sex estimation, surgical interventions, and clinical treatments. The pelvis is one of the first regions that comes to mind when it comes to sex estimation in humans, and the sacrum is particularly important in this regard. It is known that the width and concavity angle of the sacrum are higher in women than in men, but the height of the sacrum is less (Cheng & Song, 2003; Kamal *et al*., 2014; Krenn *et al*., 2022). Sex estimation is performed by techniques such as DNA analysis and osteometry. DNA analysis is the most prominent method in terms of accuracy, but it is costly and difficult compared to other methods. Therefore, simpler methods such as osteometry are preferred for sex determination. In osteometry method, knowing the anthropometric values in the region analyzed is significant in sex determination (Grewal *et al*., 2017).

The sacrum is highly effective in the movements of the columna vertebralis due to its position and the joints it makes. In addition, due to its location, it is open to many mechanical injuries together with the pelvis and os coccygis. Examples of these injuries include lumbar disc herniation, lumbar canal narrowing and sacroiliac joint dysfunction. To understand such mechanical problems, anthropometric and angular measurements in the lumbosacral region, the last mobile joint in our spine, are extremely important. The fact that changes in angles provide valuable information to surgeons and clinicians in diagnosis and treatment stages as well as surgical procedures cannot be ignored. For example, the angle between the lumbar vertebrae and the sacrum, called the "Lumbosacral Angle", is 20 degrees at birth and gradually increases in adults. This angle must be taken into consideration in surgical interventions on the spine (Cheng & Song, 2003; Matveeva *et al*., 2016).

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At the same time, in problems such as disc herniation and canal narrowing, surgeons perform stabilization with instrumentation to eliminate the problem in this region. When this procedure is performed at the L5-S1 level, it becomes more difficult compared to the upper segments. The reasons for the complexity in this region are the inclusion of the pelvis in the procedures performed at these levels, the involvement of more anatomical structures, the easier understanding of the anatomy of the lumbar region compared to the sacral region, the higher load on the screws at the levels of L5-S1 and below, and the screwing of the sacrum, which is a structure with limited movement, and the moving spine. Since the screw passes through the S1 corpus in the screwing process, a good understanding of the anatomical points and morphological measurements in the sacrum will help surgeons to prevent problems during and after the instrumentation process (Stovall Jr. *et al*., 1997; Kaptanoglu *et al*., 2003).

Many studies underline the importance of the anatomical structure of the sacrum and its relationship with other structures in the neighborhood. A good knowledge of this region is especially important in both clinical applications and surgical interventions, and it also gives us important clues about sex determination. In addition, the values in the findings of our study are a reference source for the devices/tools to be produced about the sacrum region today. In our study, we aimed to make 14 different anthropometric (Table I) and angular measurements of the sacrum and to evaluate our measurements considering sex.

MATERIAL AND METHOD

Ethical Approval. This study was approved by the Ethics Committee of Sakarya University (Approval No: 71522473/050.01.04/589). All procedures were conducted in accordance with the principles of the Declaration of Helsinki.

Study Design and Sample. This retrospective study included multidetector computed tomography (MDCT) images of 200 adult individuals (100 males and 100 females), aged 18–91 years, who had undergone radiological evaluation at Sakarya University Training and Research Hospital. Individuals with a history of spinal fracture, spinal surgery, metallic implants, congenital spinal deformity, or evident sacral variation were excluded.

Image Acquisition and Reconstruction. MDCT images were obtained from the hospital's Picture Archiving and Communication System (PACS). The scans were reconstructed into three-dimensional (3D) models using

Table I. Description of the measurements.

Measurement	Abbreviation	Definition
Height of the sacrum	SH	Distance between the promontory and the anterior apex of the sacrum.
Width of the sacrum	SW	Maximum distance between the two alae at the S1 level.
Transverse diameter of the basis ossis sacri	BTD	Maximum right–left diameter of the sacral base at the S1 level.
Sagittal diameter of the basis ossis sacri	BSD	Maximum anteroposterior diameter of the sacral base at the S1 level.
Lengths of linea transversa	LTH	Lengths of the transverse lines on the sacral surface.
Interforaminal heights	IFH	Vertical distances between adjacent anterior sacral foramina on both sides.
Sacral canal length	SCL	Distance from the cranial opening of the sacral canal to its caudal end.
Length of ala sacrum	ASL	Lateral projection length of each ala, calculated by subtracting the lateral base length from the sacral width.
Lumbosacral angle	LSA	Obtuse angle between the midline of the L5 vertebral body and the midline of the S1 vertebral body.
Sacral curvature	SC	Acute angle between lines connecting the midpoints of the superior and inferior borders of S1 and S5.
Sacral kyphosis	SK	Acute angle between lines connecting the midpoints of the superior and inferior borders of all sacral vertebrae and those of S2–S4.
Sacrococcygeal angle	SCA	Obtuse angle between a line from the promontory to the anterior midpoint of the sacrococcygeal joint and a line from the distal coccyx to the same midpoint.
Sacrococcygeal joint angle	SCJA	Acute angle between lines connecting the midpoints of the superior and inferior borders of the sacrum and those of the first coccygeal vertebra.
Coccygeal curvature	CC	Acute angle between lines connecting the midpoints of the superior and inferior borders of the first and last coccygeal vertebrae.

RadiAnt DICOM Viewer software. All linear and angular measurements were performed on these 3D reconstructions.

Measurements

A total of twenty-two morphometric parameters were evaluated, including fourteen linear and eight angular measurements of the sacrum (Table I, Fig. 1).

Linear measurements included sacral height (SH), sacral width (SW), transverse and sagittal diameters of the sacral base (BTD, BSD), linea transversa lengths (LTH1–LTH4), interforaminal heights (IFH1–IFH4), sacral canal length (SCL), and ala sacrum length (ASL).

Angular measurements included lumbosacral angle (LSA), sacral curvature (SC), sacral kyphosis (SK), sacrococcygeal angle (SCA), sacrococcygeal joint angle (SCJA), and coccygeal curvature (CC).

All measurements were performed by a single observer to minimize inter-observer variability.

Statistical Analysis. Data analysis was performed using SPSS Statistics v26.0 (IBM Corp., Armonk, NY, USA). The Shapiro–Wilk and Kolmogorov–Smirnov tests were used to assess normality. Skewness and kurtosis values between -1.5 and +1.5 were considered indicative of normal distribution. Categorical variables were analyzed using Chi-square or Fisher's exact test. For continuous variables, independent-samples t-test or one-way ANOVA was applied for normally distributed data, and the Mann–Whitney U or Kruskal–Walli's test for non-normally distributed data. A p-value <0.05 was considered statistically significant.

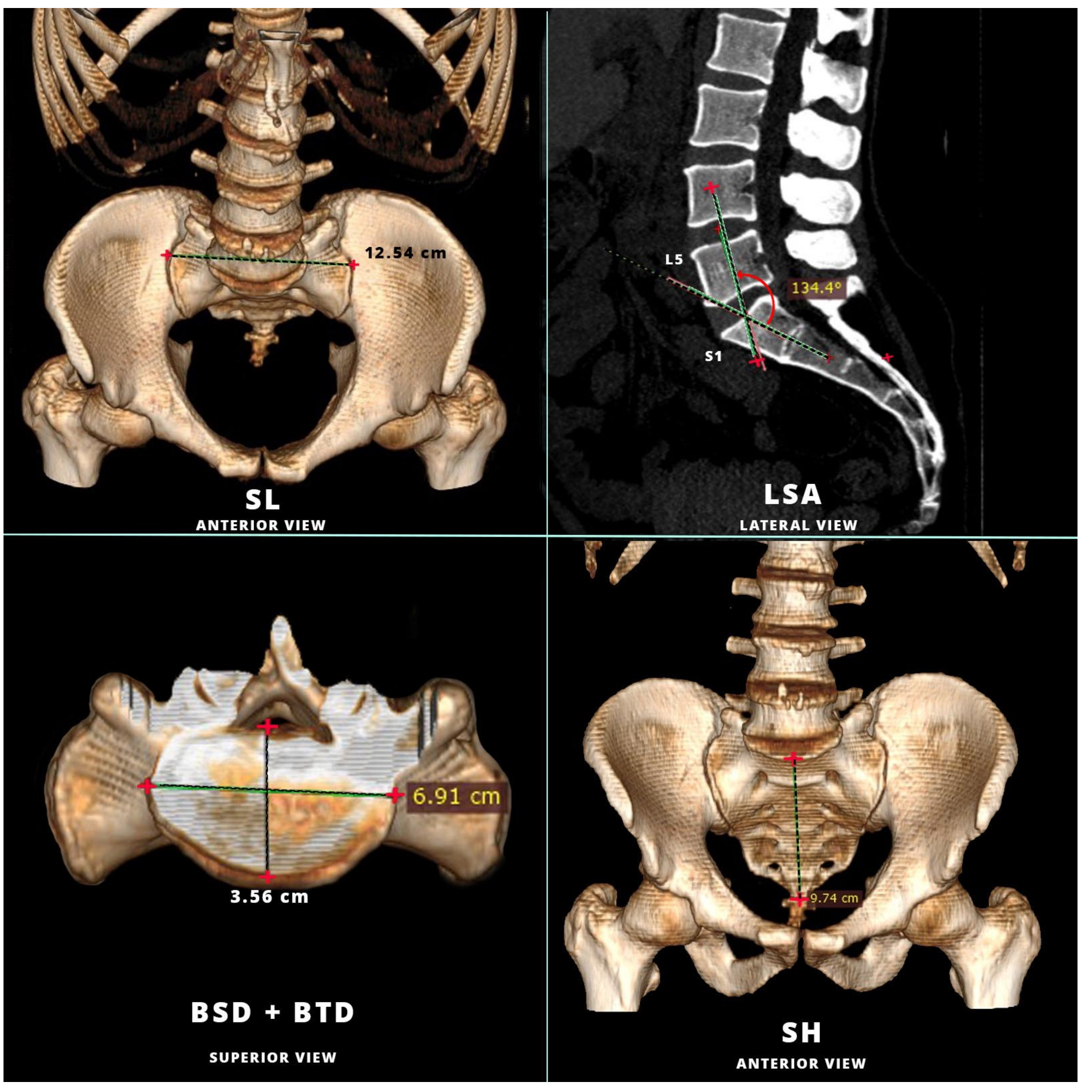

Fig. 1 Sacral length (SL), Lumbo sacral angle (LSA), Basis osis sacri sagittal diameter (BSD), Basis osis sacri transverse diameter (BTD), Sacral height (SH) measurements shown in the figure.

RESULTS

Out of the 22 sacral measurements evaluated, seven parameters showed statistically significant differences between males and females ($p<0.05$) (Table II).

- Sacral height (SH) was greater in males (p=0.020), whereas sacral width (SW) was greater in females (p=0.025).
- Sagittal diameter of the sacral base (BSD) was greater in males (p=0.010).
- Lumbosacral angle (LSA), sacral kyphosis (SK), and sacrococcygeal angle (SCA) were all significantly greater in males (p=0.042, p=0.012, and p=0.017, respectively).

Age-related changes were limited to certain parameters. Basis ossis sacri transverse diameter (BTD) decreased significantly with age (p=0.015), and SCA also showed a significant reduction in older individuals (p=0.011). No significant age-related changes were found for SH, SW, or BSD.

Linea transversa lengths (LTH1–LTH4): LTH2, LTH3, and LTH4 were significantly greater in males (p=0.001, p=0.001, and p=0.002, respectively), while LTH1 showed no significant sex difference (p=0.630). None of these parameters varied significantly with age.

Interforaminal heights (IFH1–IFH4): No significant sex differences were detected. However, age-related differences were observed for IFHD1 and IFHS1 bilaterally.

Sacral canal length (SCL) and Ala sacrum length (ASL) showed no significant differences with respect to sex or age, although ASL displayed a slight age-related decline.

Correlation analysis revealed:

- Positive correlation between SCL and SH (p=0.011).
- Negative correlation between sacral curvature and SH (p=0.008).
- LTH1 and LTH4 positively correlated with SW (p=0.036 and p=0.022, respectively).

- No significant association between SK and LSA (p=0.927).

Table II. Comparison of length and angle measurements according to sex age factors.

Measurement	Male [n: 100] X ±std	Female [n: 100] X ±std	Sig. [Sex]	Sig. [Age]	Coefficients	Adjusted R^2
SW	*11.875±0.917*	*12.171±0.965*	*p:0.025 **	*p:0.997*	*-2.42*	*-0.005*
SH	*11.080±1.41*	*10.045±1.44*	*p:0.020**	*p:0.270*	*-0.004*	*+0.001*
BTD	*5.346±0.738*	*5.393±0.830*	*p:0.67*	*p:0.015 **	*+0.008*	*+0.024*
BSD	*4.408±0.513*	*4.140±0.599*	*p:0.01**	*p:0.153*	*+0.003*	*+0.005*
IFHD1	*1.280±0.232*	*1.231±0.199*	*p:0.109*	*p:0.020*	*-0.03*	*+0.041*
IFHD2	*1.061±0.164*	*0.982±0.177*	*p:0.9*	*p:0.098*	*-0.001*	*+0.009*
IFHD3	*0.927±0.662*	*0.920±0.926*	*p:0.95*	*p: 0.413*	*-0.003*	*-0.002*
IFHS1	*1.271±0.239*	*1.249±0.192*	*p:0.46*	*p:0.000**	*-0.003*	*+0.067*
IFHS2	*1.050±0.164*	*0.982±0.177*	*p:0.90*	*p:0.081*	*+0.015*	*+0.009*
IFHS3	*0.938±0.662*	*0.931±0.926*	*p:0.95*	*p:0.312*	*-0.003*	*-0.002*
SCL	*9.787±1.218*	*9.506±1.245*	*p:0.108*	*p:0.645*	*+0.002*	*-0.004*
ASL	*6.613±1.063*	*6.865±1.894*	*p:0.248*	*p:0.228*	*-0.008*	*+0.002*
LSA	*130.75±14.046*	*126.28±16.751*	*p:0.042 **	*p:0.376*	*+0.057*	*-0.001*
SC	*45.81±7.266*	*46.73±8.770*	*p:0.420*	*p:0.279*	*-0.037*	*+0.001*
SK	*38.53±9.698*	*35.18±8.912*	*p:0.012 **	*p:0.134*	*+0.059*	*+0.006*
SCA	*113.907±10.964*	*109.924±12.383*	*p:0.017**	*p:0.003**	*+0.0143*	*+0.038*
SCJA	*17.101±5.560*	*17.155±6.298*	*p:0.949*	*p:0.673*	*-0.010*	*+0.004*
CC	*33.22±8.644*	*32.73±9.614*	*p:0.700*	*p:0.220*	*+0.046*	*+0.003*
LTH1	*3.271±0.307*	*3.247±0.412*	*p:0.636*	*p:0.446*	*-0.001*	*-0.002*
LTH2	*3.019±0.405*	*2.765± 0.479*	*p:0.001**	*p:0.248*	*+0.002*	*+0.002*
LTH3	*2.724±0.282*	*2.494±0.318*	*p:0.001**	*p:0.014 **	*+0.003*	*+0.025*
LTH4	*2.556±0.297*	*2.407±0.362*	*p:0.002**	*p:0.105*	*+0.002*	*+0.008*

*: p<0,05, X: Mean, ±SD

DISCUSSION

This study provides a comprehensive three-dimensional morphometric analysis of the human sacrum, integrating both linear and angular parameters obtained through high-resolution multidetector computed tomography (MDCT). Our findings underscore the value of sacral metrics in sex estimation and highlight specific anatomical features that may assist clinicians in spinal and pelvic surgical planning.

As a result of the literature review, it has been observed that metric studies on radiological images are easier to perform, and higher accuracy rates are obtained compared to morphological methods for issues such as sex estimation. The analysis, grouping and recording of data can be done more efficiently with these measurement techniques. One of the main reasons for this is that the differences between bones can be seen more clearly in computer-based measurements and their measurement is easier than the morphological method (Kimmerle *et al*., 2008; Kranioti *et al*., 2009).

Many methods are used for angle and length measurements on the spine in the human body. These methods include flexible rulers, radiography, spinal mouse, inclinometer, and some computer software. Radiography method is an effective method that is frequently preferred in studies due to its higher accuracy rate compared to other methods (accuracy close to 95 %), practicality of measurement, retrospective acquisition of images and the opportunity to reach a larger number of participants (Cobb, 1948; Souza Filho *et al*., 2007; Karacan *et al*., 2021).

A good knowledge of the sacrum bone and the region where it is located is especially important in both clinical and surgical interventions and gives us important clues about sex determination. In the studies, different measurements of the sacrum were made in different sample groups.

When we examined the literature, Basaloglu *et al*. (2005) in a study performed on 60 dry bones, the mean SH value was expressed as 10.43±1.24 cm in males and 10.20±1.02 cm in females and emphasized that these values were statistically insignificant in terms of sex ($p > 0.005$). In terms of SH value, our findings are females and stated that the difference was significant (p:0.001) (Özandaç Polat *et al*., 2020), different from the study of Basaloglu *et al*. (2005). We think that this difference may be due to the small number of participants in the study of Basaloglu *et al*. (2005) and individual errors that may be made when using calipers on dry bones.

Acar *et al*. (2018) in a study performed on 100 radiological images with CT method, the mean SL was 10.86±8.43 cm in women and 10.81±12.55 cm in men, and it was reported that there was no statistically significant difference in terms of sex in these results ($p>0.005$). Benazzi *et al*. (2009) in a study on 111 dry bones, the SL value was found to be 11.23±0.68 cm in males and 11.23±0.63 cm in females, similar to that of males, and it was reported that there was no statistically significant difference in terms of sex ($p>0.05$). In order to measure these values, camera shots were taken over the bones and then these shots were drawn on the AutoCAD program. Our study is in parallel with the study conducted by Basaloglu *et al*. (2005). We think that the narrow number of participants in the study conducted by Acar *et al*. (2018) and the use of a different method in the study conducted by Benazzi *et al*. (2009) led to this difference.

In the study by Benazzi *et al*. (2009), the mean BTD value was 5±0.37 cm in males and 4.39±0.38 cm in females, while in the study by Etli *et al*. (2019) the mean BTD value was 5.55±5.1 cm in males and 5.25±5.2 cm in females. In both studies, it was emphasized that there was a significant difference between sexes in terms of BTD value ($p<0.005$). These results in SL do not overlap with our study in terms of sex factor.

Etli *et al*. (2019) using 480 CT images, the mean BSD value was calculated as 3.56±3.2 cm in males and 3.28±2.9 cm in females, and they reported that this value revealed a statistically significant difference in terms of sex, and this result is in line with our study (Etli *et al*., 2019)).

Bakici *et al*. (2021) In a study performed on 100 CT images, the mean values of linea transversa length were 2.80±0.28 cm for LTH1, 2.66±0.23 cm for LTH2, 2.50±0.20 cm and 2.47±0.20 cm for LTH3 in females, respectively; 3.00±0.35 cm for LTH1, 2.93±0.28 cm for LTH2, 2.78±0.24 cm for LTH3 and 2.59±0.24 cm for LTH4 in males and emphasized that there was a statistically significant difference in terms of sex for each of these values ($p<0.05$). Pandey *et al*. (2003) reported that there was no statistically significant result in terms of sex for interforaminal height values in their study.

Janamiri *et al*. (2018) measured the mean value of ASL as 5.66 cm for males and 6.32 cm for females in their study using calipers on a total of 116 dry bones. When ASL was compared in terms of sex, they reported that there was no statistically significant difference. In our study, similar to the study by Janamiri *et al*. (2018), it was emphasized that there was no statistically significant difference in terms of sex.

Okpala *et al*. (2014) in their study of 274 normal radiographic images, the lumbosacral angle values were 43.37° in males and 45.25° in females. In contrast to our study, narrow angle value was used in the LSA value) and emphasized that these values were not significantly different in terms of age and sex (p>0.005). Our study did not show parallel findings with the study conducted by Okpala *et al*. (2014).

In a study conducted by McKay *et al*. (2018) on 95 participants, the mean SK angle of women was found to be 31.5° degrees while it was 39.4° degrees in men, and they concluded that the difference between these values was statistically significant in terms of sex (p*:0.0031). These results support our study.

Gupta *et al*. (2018) in a study on 107 CT images found the mean value of the SCA angle to be 128.4° in women and 124.5° in men, and in contrast to our study, they reported that this angle did not reveal asignificant difference in terms of sex.

Strengths and Limitations

The primary strength of our study lies in its use of MDCT-based 3D reconstructions, which minimize observer error and allow high precision in angular and spatial measurements. Additionally, our inclusion of both male and female participants across a wide age range adds robustness and generalizability.

However, certain limitations should be acknowledged. First, the retrospective nature of the study limited our control over subject selection. Second, the absence of inter-observer reliability analysis may affect reproducibility. Finally, while our study offers strong discriminative value for sex estimation, further validation through discriminant function analysis or ROC curves would enhance forensic applicability.

CONCLUSION

The present study demonstrates that several sacral morphometric parameters, particularly SH, SW, BSD, LSA, SK, and SCA, show significant sex-related differences, while age-related changes are more limited and confined to specific dimensions. These findings provide a robust reference dataset for forensic anthropology, surgical planning, and biomechanical modeling of the lumbosacral region.

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ÇELIK, H. & KARACAN, K. Análisis morfométrico y angular tridimensional del sacro humano: implicaciones para la estimación del sexo y su aplicación clínica mediante TC multidetector. *Int. J. Morphol., 44(1)*:192-198, 2026.

RESUMEN: Comprender las características morfométricas y angulares del sacro es fundamental no solo para intervenciones clínicas y quirúrgicas, sino también para una estimación fiable del sexo en entornos forenses y antropológicos. A pesar de su importancia, los análisis exhaustivos que integran mediciones lineales y angulares a partir de imágenes de alta resolución siguen siendo limitados. Este estudio tuvo como objetivo evaluar 22 parámetros antropométricos y angulares del sacro humano en relación con el sexo y la edad, utilizando reconstrucciones tridimensionales obtenidas a partir de imágenes de tomografía computarizada multidetector. Se analizaron retrospectivamente imágenes radiológicas de 100 mujeres y 100 hombres, entre 18 y 91 años. Las imágenes se obtuvieron mediante tomografía computarizada multidetector y se convirtieron en modelos tridimensionales mediante el software Radiant Dicom Viewer. Se realizaron catorce mediciones angulares y de longitud en el sacro, y el análisis estadístico se realizó con SPSS. El sexo mostró un efecto significativo en la altura y la anchura del sacro, el diámetro sagital de la base del sacro, el ángulo lumbosacro, la cifosis sacra y el ángulo sacrococcígeo (p < 0,05). Algunos parámetros mostraron cambios dependientes de la edad, en particular una disminución del ángulo sacrococcígeo y del diámetro transversal con la edad. Este estudio proporciona un conjunto completo de datos morfométricos de referencia para el sacro, combinando métricas lineales y angulares en un contexto de imágenes 3D. Los hallazgos subrayan la relevancia de parámetros sacros específicos para la estimación del sexo y respaldan su valor clínico en la planificación preoperatoria y la instrumentación espinal.

PALABRAS CLAVE: Sacro; Cóccix; Tomografía Computarizada; Determinación del sexo.

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