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BOLU ABANT İZZET BAYSAL UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
ANATOMY

EXAMINATION OF THE CHANGES IN THE PARAMETERS OF THE SACRUM RELATED TO GENDER AND AGE

MASTER OF SCIENCE

BASEL MALAYSHEH

ACADEMIC SUPERVISOR
Prof. Dr. İbrahim KÜRTÜL

BOLU, TEMMUZ - 2024

APPROVAL OF THE THESIS

Examination of the changes in the parameters of the sacrum related to gender and age submitted by **Basel Malaysheh** and defended before the Examining Committee Members listed below in partial fulfillment of the requirements for the degree of **Master of Science** in **ANATOMY, Institute of Graduate Studies of Bolu Abant Izzet Baysal University in 4.07.2024** by

Examining Committee Members	**Signature**
Supervisor Prof. Dr. İbrahim KÜRTÜL Bolu Abant İzzet Baysal University	
Member Assoc. Prof. Gamze TAŞKIN ŞENOL Bolu Abant İzzet Baysal University	
Member Assoc. Prof. Şeyma TOY Karabük University	

Prof. Dr. İbrahim KÜRTÜL

Director of Institute of Graduate Studies

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Basel Malaysheh

ABSTRACT

EXAMINATION OF THE CHANGES IN THE PARAMETERS OF THE SACRUM RELATED TO GENDER AND AGE
MSC THESIS
BASEL MALAYSHEH
BOLU ABANT IZZET BAYSAL UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF ANATOMY
(SUPERVISOR: PROF. DR. İBRAHIM KÜRTÜL)

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XI + 40

The study aimed to investigate gender and age-related changes in the parameters of the sacrum. The study was conducted at Bolu Abant İzzet Baysal University using the Picture Archiving and Communication System (PACS) from which 200 archived images of healthy individuals aged 16-59 years. Individuals in the study were divided into four groups according to age. The parameters that were measured in the study were sacral angles (SA), anterioposterior length of the canalis sacralis (ALCS), the width of the canalis sacralis (WCS), sacral length (SL), sacral width (SW) and sacral index (SI). As a result of the study, age was a statistically significant variable between groups. Gender was a significant variable in the fourth group. In the analyses performed to determine the difference between the groups and within each group based on gender, there were no statistically significant differences in the SA, ADCS, and SL values between all groups and between the individuals forming each group. The WCS variable between groups was not statistically significant, however, the difference between the individuals in terms of gender was statistically significant in the first group, but not in the other groups (p-value <0.05). SW was significantly variable between groups, but within groups. SI was significantly variable based on gender in group 2, however, SI was not significantly variable within the other groups and between groups. Sacrum parameters could be helpful in gender determination.

KEYWORDS: Sacrum, Anatomy, Computed Tomography, Sacral Length, Sacral Width.

ÖZET

EXAMINATION OF THE CHANGES IN THE PARAMETERS OF THE SACRUM RELATED TO GENDER AND AGE
YÜKSEK LISANS TEZI
BASEL MALAYSHEH
BOLU ABANT İZZET BAYSAL ÜNIVERSITESI
LISANSÜSTÜ EĞITIM ENSTITÜSÜ
ANATOMY ANABİLİM DALI
(TEZ DANIŞMANI: PROF. DR. IBRAHİM KÜRTÜL)

BOLU, TEMMUZ - 2024
XI+40

Çalışmanın amacı sakrum parametrelerindeki cinsiyet ve yaşa bağlı değişiklikleri araştırmaktır. Çalışma, Bolu Abant İzzet Baysal Üniversitesi'nde, 16-59 yaş arası sağlıklı bireylere ait 200 arşivlenmiş görüntünün bulunduğu Picture Archiving and Communication System (PACS) kullanılarak gerçekleştirilmiştir. Çalışmaya katılan bireyler yaşlarına göre dört gruba ayrıldı. Çalışmada ölçülen parametreler sakral açı (SA), canalis sacralis'in anterioposterior uzunluğu (ALCS), canalis sacralis'in genişliği (WCS), sakral uzunluk (SL), sakral genişlik (SW) ve sakral indeks (SI) idi. Çalışma sonucunda yaş, gruplar arasında istatistiksel olarak anlamlıdır. Yaş değişkeinde cinsiyet ise dördüncü grupta anlamlı olarak bulunmuştur. Cinsiyete göre gruplar arasındaki ve her bir grubun kendi içindeki farkı belirlemek için yapılan analizlerde SA, ADCS ve SL değerlerinde tüm gruplar arasında ve her bir grubu oluşturan bireyler arasında istatistiksel olarak anlamlı bir fark bulunmamıştır. Gruplar arasındaki WCS değişkeni istatistiksel olarak anlamlı değildi, ancak cinsiyet açısından bireyler arasındaki fark ilk grupta istatistiksel olarak anlamlıydı, ancak diğer gruplarda anlamlı değildi (p-değeri <0.05). SW gruplar arasında farklılığı anlamlıdır, ancak grupları oluşturan bireylerin cinsiyet farklılığı anlamlı değildir. SI, grup 2'de cinsiyete bağlı olarak önemli ölçüde farklılık göstermiştir, ancak SI için gruplar arası farklılık anlamlı değildir.

ANAHTAR KELİMELER: Sakrum, Anatomi, Sakral uzunluk ve Sakral genişlik, Bilgisayarlı tomografi.

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LIST OF ABBREVIATIONS AND SYMBOLS

ALCS	: Anterioposterior Length of the Canalis Sacralis
CT	: Computed Tomography
DICOM	: Digital Imaging and Communications in Medicine
Max	: Maximum
Med	: Median
Min	: Minimum
PACs	: Picture Archiving and Communication System
SA	: Sacral Angles
SI	: Sacral Index
SL	: Sacral Length
SW	: Sacral Width
SD	: Standard Deviation
TFV	: Two-Factor Variance
WCS	: Width of the Canalis Sacralis
MPR	: Multiplanar Reformation
RDv	: Radiant Dicom Viewer
3D	: Three Dimensional

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1. INTRODUCTION

The human spine, with its 24 articulating vertebrae, may be compared to a complicated column that combines substantial structural support with limited mobility. The anatomical structure of the spinal regions is influenced by the capacity of the vertebral components to support weight, and this appears to be especially the case for the sacrum (1). It is, which is spoken of as the foundation of the human body, significant because it connects the iliac bones to the spine and is essential for hip stability (2).

The sacrum forms the posteriosuperior wall of the pelvic cavity and is a big, triangular vertebrae that have cemented together, Its blunted caudal apex connects with the coccyx bone, and its superior wide base connects with the fifth lumbar vertebra at the lumbosacral angle. It interacts with the sacral canal through four pairs of sacral foramina (3).

Genetic and environmental factors influence the skeletal development of different populations, impacting morphological and metric evaluations of biological profiles. Therefore, unique equations are required for every population in order to improve the precision of identification in the sacrum bone. By Using multiplanar reconstruction (MPR) in three dimensions (4).

The multi-planar reconstruction (MPR) technique can even transfer several sections of the bones onto the same plane. Several literature reports have documented and explored both the advantages and constraints of the procedure in their articles (5). Likewise, the MPR technique has been applied in this study, using the length, width, and depth of the sacrum, which shows the exact shape of the bone. With this in mind, this study carried out on the images obtained from the archive system Picture Archiving and Communication System (PACs) of Bolu Abant İzzet Baysal University Education and Research Hospital, has focused on investigating the changes in certain parameters of the sacrum in relation with the gender and age. The findings will provide essential structural information about pertinent literature and the shapes of the sacrum. The results obtained hereby support surely the idea that the combination of these approaches will probably become common in clinical approaches in the future (5).

2. AIM AND SCOPE OF THE STUDY

2.1 Sacral Bone Embryology

The vertebrae are formed from the sclerotomes part of the somites generated by the paraxial mesoderm, which exists on both sides of the neural tube. The paraxial mesoderm is separated craniocaudally during the first segmentation phase, which occurs between the 20^{th} and 30^{th} days of development. This process is linked with the creation of segmented structures such as peripheral spinal nerves and the axial muscles. The sclerotomes later move throughout the notochord and spinal cord, joining opposing somites and contributing to vertebral formation (6,7). As development advances, the cranial half of each sclerotome fuses with the adjacent caudal half of the adjacent sclerotome, forming a vertebra and linking the intersegmented muscles with the same somites (6-8). A typical cartilaginous vertebra begins to develop around the 12th week after ovulation and consists of a centrum, two half-neural arches with peduncles, and articulating and transverse processes (9).

Around the end of the first month of embryonic development, the segmented axial skeleton shape is established (7). The sacrum is initially discovered as a permanent cartilaginous unit at the last stage of the embryonic phase with extra alar parts that are not present in the lumbar region. The connection of these cartilaginous sacral elements begins between 44-48 days after ovulation, and the entire five sacral parts participate in fusion in 53-54 days post-ovulatory (7,10).
During the first three to six months of pregnancy, the Endochondral ossifying process of the cartilaginous sacral vertebrae starts in the major source ossification centers and lasts until delivery. These disconnected osseous components then merge inside each vertebral level at the age of about two to six years, resulting in five separated sacral vertebrae. The fusion of the five sacral vertebrae begins during puberty at approximately 25 years resulting in a complete union of the five sacral vertebrae(10).

2.2 Sacral Bone Anatomy

The sacrum is a large, irregular, triangular, wedge-shaped bone in adults found in the lower end of the spine. It originally involves five primitive vertebrae fused, with a concave anterior. The sacrum gives strength and stability to the pelvis and conveys body weight to the pelvic girdle via the sacroiliac joints. Additionally, There are four pairs of sacral foramina at the anterior and posterior surfaces of the sacrum through which the rami of the first four sacral nerves and their associated blood vessels come in and out. The fifth lumbar vertebra might be merged into the sacrum, however, the first sacral vertebra might break from the sacrum and resemble a sixth lumbar vertebra, resulting in lumbarization of the first sacral vertebra. The four transverse lines show where the sacral vertebrae were fused (10-13).

2.2.1 Anterior Part of Sacral bone

The sacrum's front surface is concave superoinferiorly and mediolaterally. The anterior side is smooth and lies anteroinferior in the pelvic cavity. The medial section consists of five fused anterior surfaces of the sacral vertebral bodies and is linked by four transverse lines. Additionally, four pairs of anterior sacral foramina carry the ventral rami of the first four sacral nerves and their associated blood vessels. The foramina are oval-shaped and oriented laterally with the first sacral vertebra foramina sitting about 15° inferior to the horizontal plane. The region between the foramina is known as the costal elements or functional pedicles, and it is where ilio sacral screws are passed through (10-13).

The union of the costal elements, which is known as the lateral sacral mass, is located laterally to the foramina. The first sacral vertebral body is the biggest, and the wide sacral alae in the superolateral region of the sacrum indicate the location of costal/rib fusion in the upper sacral vertebrae. The sacral promontory, defined by the protruding boundary at the base of the sacrum, is a noticeable marker in females during pelvic examination, labor, and delivery (10-13).

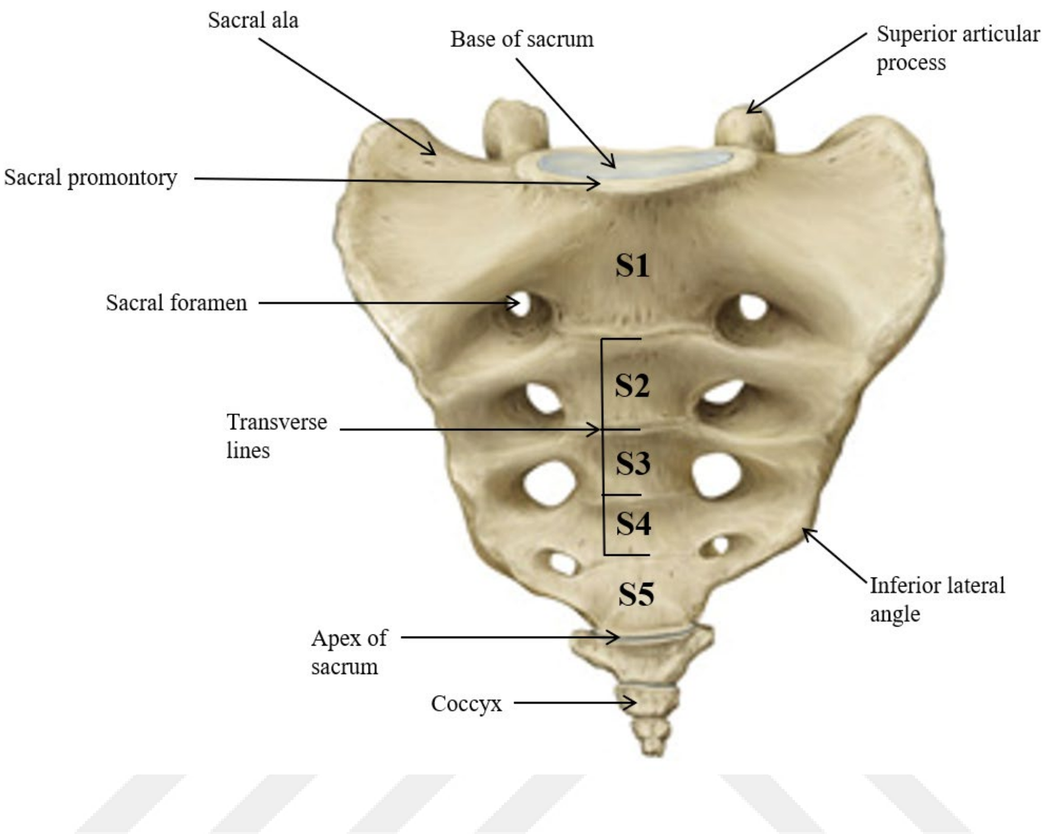

Figure 2.1. Anterior Part of Sacral bone

2.2.2 Lateral Part of the Sacral bone

The Lateral side of the sacrum is next to the posterior sacral foramina. The lateral sacral crest forms the medial boundary, while a roughly L-shaped auricular surface articulates with the innominate to produce the sacroiliac joint. The number of sacral segments engaged in the auricular surface of the sacrum ranges from the first sacral vertebra to the second sacral vertebra, occasionally as low as the third sacral vertebra, particularly in males, which is probably due to increased weight by way of the sacroiliac articulation (10-13).

The sacral tuberosity, which is located between the lateral sacral crest and the auricular surface, is a roughened surface with depressions for ligament connection. The sacral tuberosity is another surface of the sacrum that connects to the ilium to produce the sacroiliac joint. The lateral sacral mass is frequently utilized for ilio-sacral screw implantation (10-13).

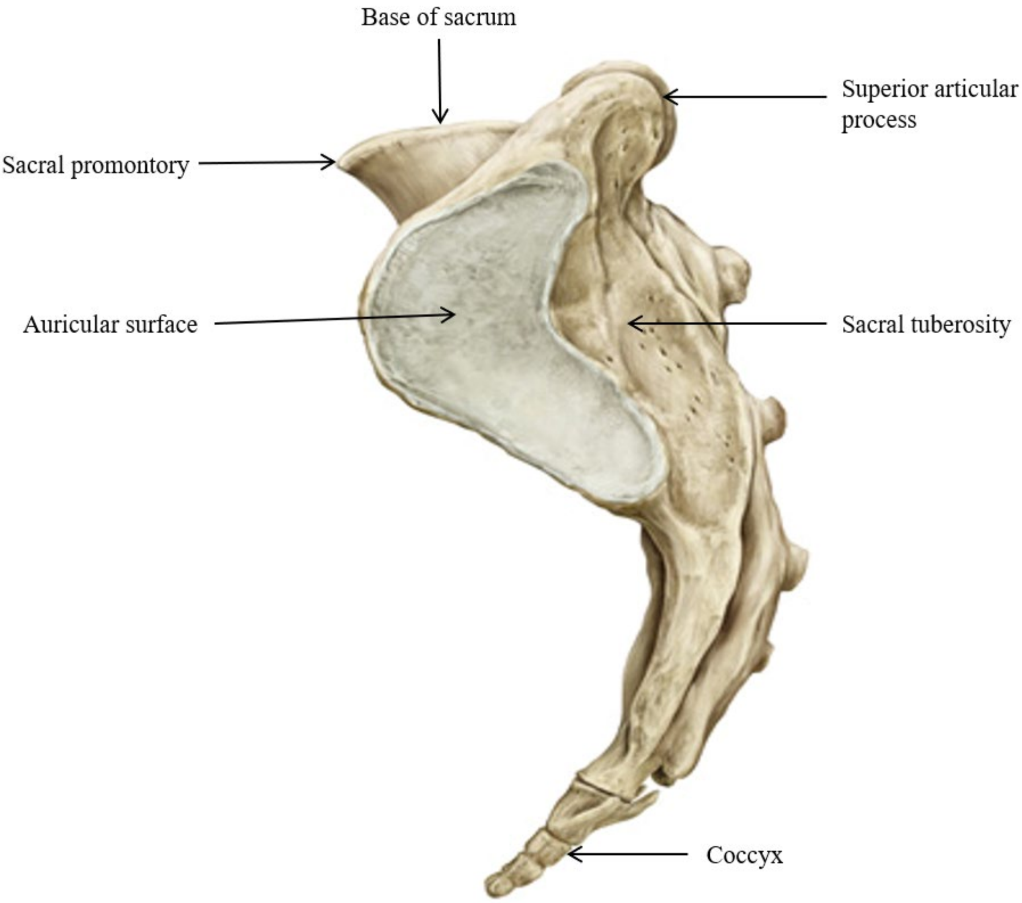

Figure 2.2. Lateral Part of Sacral bone.

2.2.3 Posterior Part of the Sacral bone

The sacrum takes an uneven and convex form superoinferiorly, which corresponds to its concave front surface. This surface is rough, faces posterosuperior, and it has various landmarks associated with anatomy. The median sacral crest is a series of elevations in the midline that represent the fused spinous processes, with the first sacral vertebra tubercle usually being prominent and distinct from the rest. The paired lateral elevations, known as the lateral sacral crest, represent the fused transverse processes of the sacral vertebrae. The laminae were fused to produce the sacral groove, which is found on every side of the median sacral crest, and the intermediate sacral crest, which depicts the joined articular processes, is located lateral to the groove (10-13).

The intermediate sacral crest descends to generate the sacral cornu, or horns, which indicate the articular process of the fifth sacral vertebra. The sacral cornu is generated when the laminae of the fifth sacral vertebrae fail to connect one another in the midline, together with the spinous process, resulting in the creation of the sacral hiatus. This hiatus is an inverted 'V' right below the median sacral crest at the inferior entrance of the sacrum, and it is connected with the sacral canal superiorly. The four pairs of posterior sacral foramina, which are smaller than the anterior sacral foramina, transmit the dorsal rami of the first and fourth sacral nerves and associated blood vessels and replace the intervertebral foramina that became enclosed by sacral vertebrae fusion (10-13).

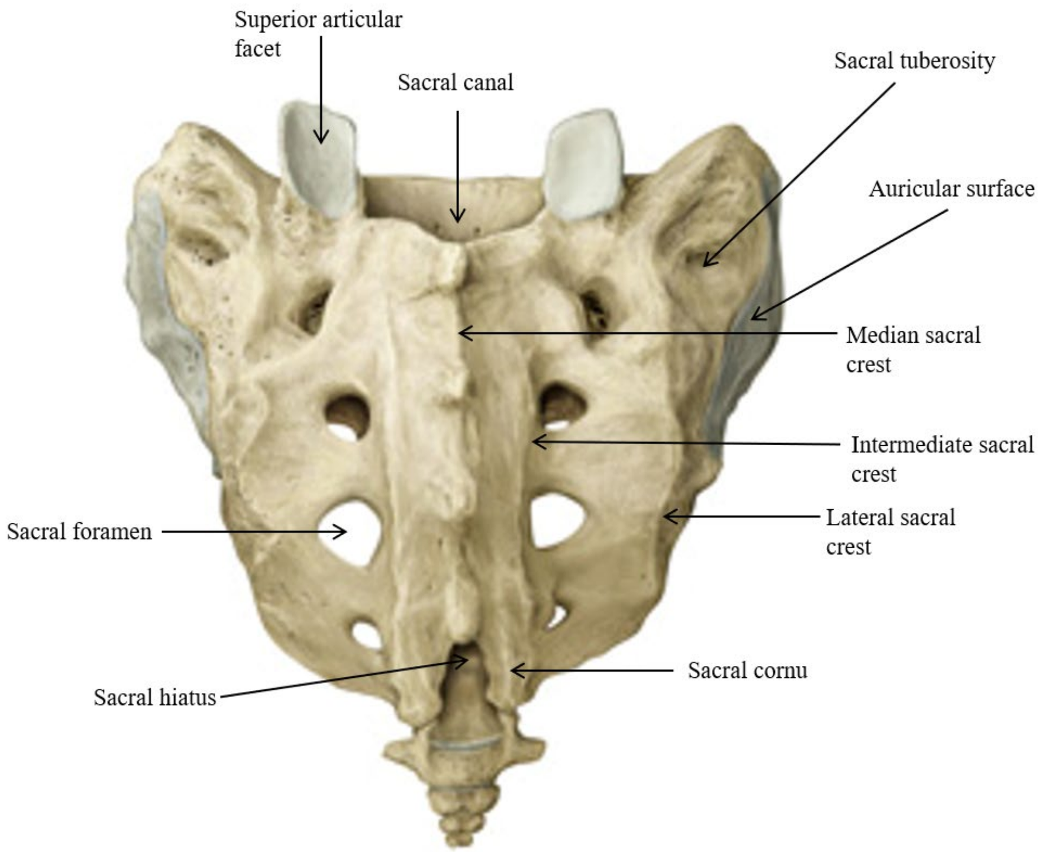

Figure 2.3. Posterior Part of Sacral bone

2.2.4 The Apex of the Sacral Bone

The apex of the sacrum is the thin causal inferior section. The fifth sacral vertebral body features an oval-shaped facet for articulation with the coccyx. The apex projects posteriorly, increasing the size of the pelvic cavity. The apex of the sacrum is the base of the coccyx where its flattened surface connects the sacrum with the first coccygeal segment, which merges later (10-13).

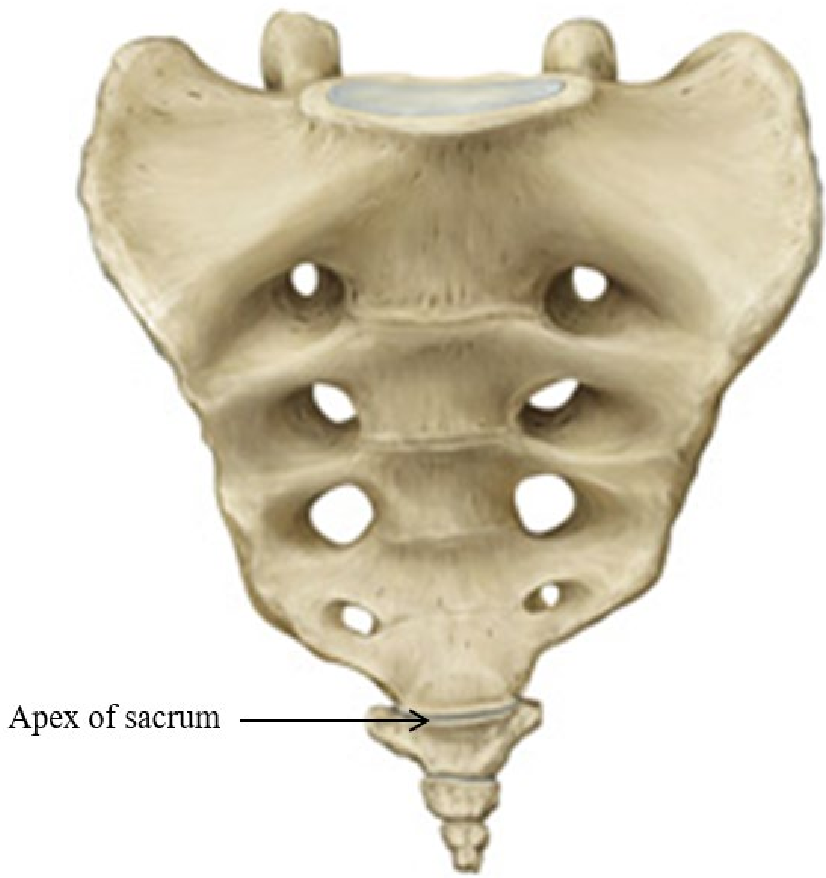

Figure 2.4. Apex of Sacral bone

2.2.5 The Base of the Sacral bone

The base of the sacrum is formed by both the sacral alae and the body of the first sacral vertebra. It represents the widest and largest part of the sacrum and is pointed forward and upward. It articulates with the fifth lumbar vertebra at its large oval middle area creating the lumbosacral joint. In the general population, sacralization of the fifth lumbar vertebra occurs when the fifth lumbar vertebra is fully or unilaterally merged with the first sacral vertebra, particularly in men, and frequently contributes to the formation of the auricular surface of the sacrum.

Male axial skeleton increases the load on the fifth lumbar and contributes to the fusion with the first sacral vertebra forming a larger auricular surface, whereas in females, lumbarization of the first sacral vertebra into the fifth lumbar vertebra is more common where the first sacral vertebra does not participate in the formation of the sacral auricular area. Lateral to this foramen are the paired superior articular processes which engage with the inferior articular processes of the fifth lumbar vertebra, providing weight transfer to the upper vertebrae via the lumbosacral junction (10-13).

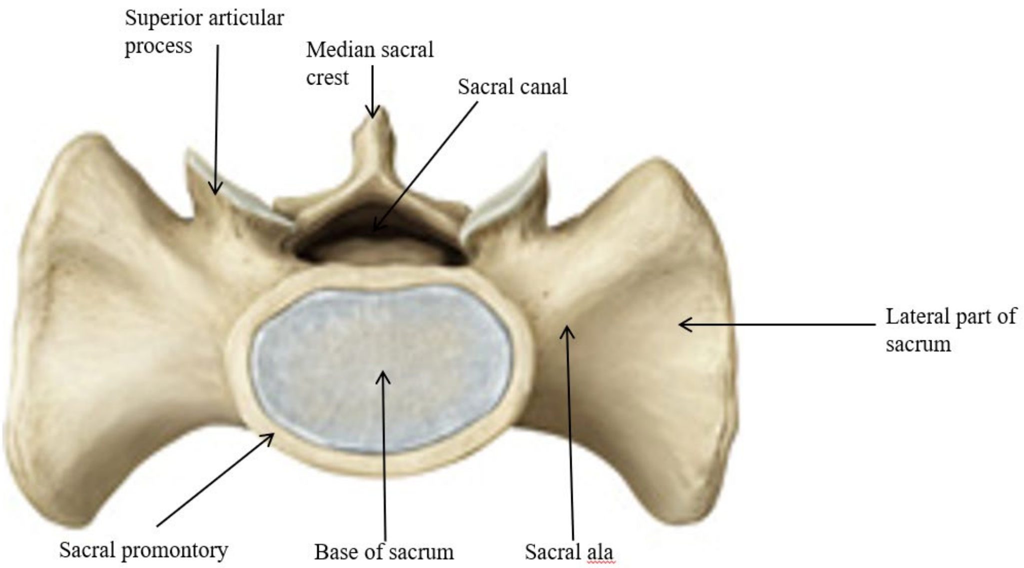

Figure 2.5. Base of Sacral bone

Distinctive differences are observed in the musculoskeletal anatomy between males and females. Females tend to have different characteristics of specific bones and bony features than males, which is explained by both genetic and environmental factors. These variations could be associated with gender differences in clinical pathology and symptomology such as differences in shoulder impingement; laxity and idiopathic capsulitis; elbow tendinosis; carpal tunnel syndrome; hip fracture and labral tears (14). Gender-based differences were also reported in the body of the first sacral vertebra and could be a useful bone for gender determination, with the first sacral vertebra in the male having higher values than the first sacral vertebra in the female looked at parameters. The study developed new formulas and parameters for S1 for gender determination, which may be utilized to identify human remains using MRI. This approach can be useful for both skeleton and fleshy remnants (15).

A predictive usefulness of anterior sacral curvature for gender determination from skeletonized human remains was previously documented, where males have considerably more sacral curvature than females at the S2-S3 and S3-S4 articulations (16). The correct estimates for the discriminant function range from 66-72%. The degree of anterior sacral curvature is used for gender determination only when other trustworthy markers are not available because sacral curvature measurements are not as accurate as other skeletal features in determining gender. Research on healthy individuals using the three-dimensional (3D) computed tomography scan-based system has revealed a direct relationship between age and gender to the variations in the investigated proximal femur anatomical parameters (17).

As the literature is surveyed there have been several studies on the vertebral column by the use of CT images (17, 18). One study analyzed the frequency of cervical ribs on CT scans of the cervical spine to evaluate their prevalence and proportion of reported cases. A retrospective examination of 3404 consecutive CT scans of the cervical spine of adult patients and reports was conducted to identify the existence and reporting of cervical ribs. A total of 2.0% of the population had cervical ribs. Of 67 individuals with cervical ribs, 27 had bilateral ribs. Women had double the frequency of cervical ribs as males (2.8% vs. 1.4%).

A previous retrospective study using CT scans concerning the femoral calcar, which is a vertical plate of compact bone with a uniform anatomical structure performing a strong mechanical role in the upper femur, assessed the form, size, and density of the femoral calcar. It was revealed that males had greater femoral cavity and calcar dimensions, which were also strongly connected with their height and weight. The findings may improve our understanding of hip fracture patterns and suggest new designs for hip arthroplasties (19).

The MPR approach has the ability to transfer many bone sections onto the same plane. Several research publications have recorded and addressed both the benefits and limitations of the method in their studies. Similarly, the MPR approach was used in this study to determine the precise structure of the sacrum by measuring its length, breadth, and depth. With this in mind, the purpose of this study, which was conducted on images obtained from the Picture Archiving and Communication System (PACs) of Bolu Abant İzzet Baysal University Education and Research Hospital, was to investigate the changes in certain parameters of the sacrum in relation to age and gender. These results will give important structural details on pertinent research and sacral forms. The results achieved here clearly support the concept that the combination of these techniques will most likely become popular in therapeutic interventions in the future.

3. MATERIALS AND METHODS

3.2 Ethical consideration

This study was carried out on 200 individuals (100 males, 100 females) aged 16-59 years who were admitted to Bolu Abant İzzet Baysal University Education and Research Center and who did not have any pathological condition that could affect Computed Tomography (CT) images of the sacrum bone. The Clinical Research Ethics Committee approved the trial, with decision number 2023/202. It began with the authorization of the ethics committee.

3.3 Image scanning and processing

Images of 200 individuals (100 males and 100 females) were obtained from the Picture Archiving and Communication System (PACs) archive system of Bolu Abant İzzet Baysal University Education and Research Hospital and images that did not meet the criteria were excluded. The sacrum CT image included in the protocol was selected. Variables were measured by transferring the images from the PACs system to the Radiant Dicom viewer (RDv) program in Digital Imaging and Communications in Medicine (DICOM) format. For the measurement of some parameters, all images in 3D multiplanar reformation (MPR) format were brought to an orthogonal plane to measure population and sample characteristics. The main screen of the RDv program is shown in Figure 3.1.

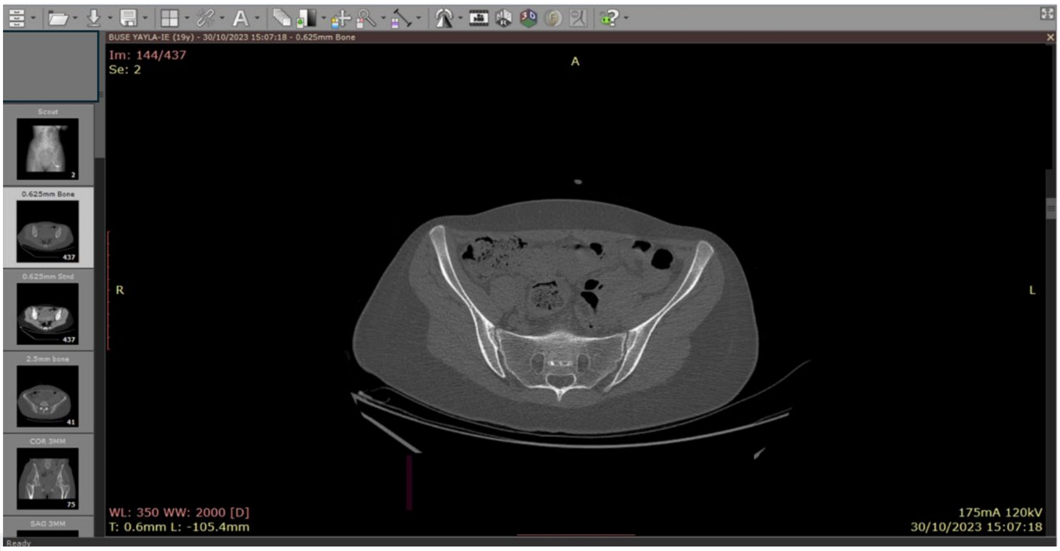

Figure 3.1. Program's main screen (The main screen after the image received in Dicom format from the PACS system is transferred to the RDv program.)

3.4 Measurement methods

The parameters that were measured in the study were sacral angles (SA), anterioposterior length of the canalis sacralis (ALCS), width of the canalis sacralis (WCS), sacral sacral length (SL), sacral width (SW) and sacral index (SI). The representation of the variables is presented in Figures 3.2, 3.3, 3.4, 3.5, and 3.6.

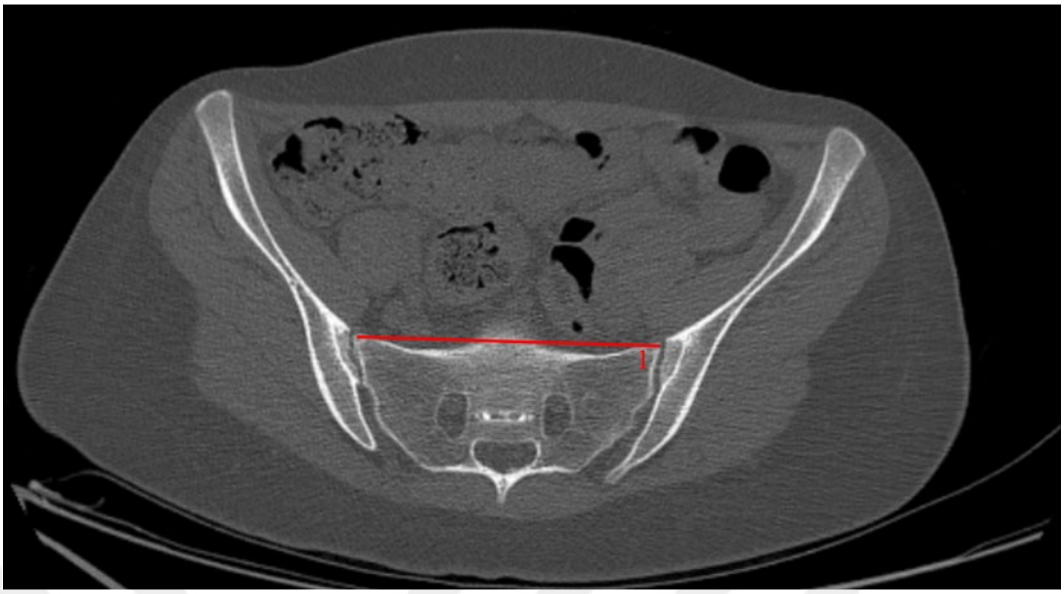

Figure 3.2. The measurements of sacral width (SW). (Representation of the SW variable in the RDv program of the image received from the PACS system in Dicom format

Figure 3.4. The measurements of anterioposterior length of the canalis sacralis (ALCS). (Representation of the ALCS variable in the RDv program of the image received from the PACS system in Dicom format)

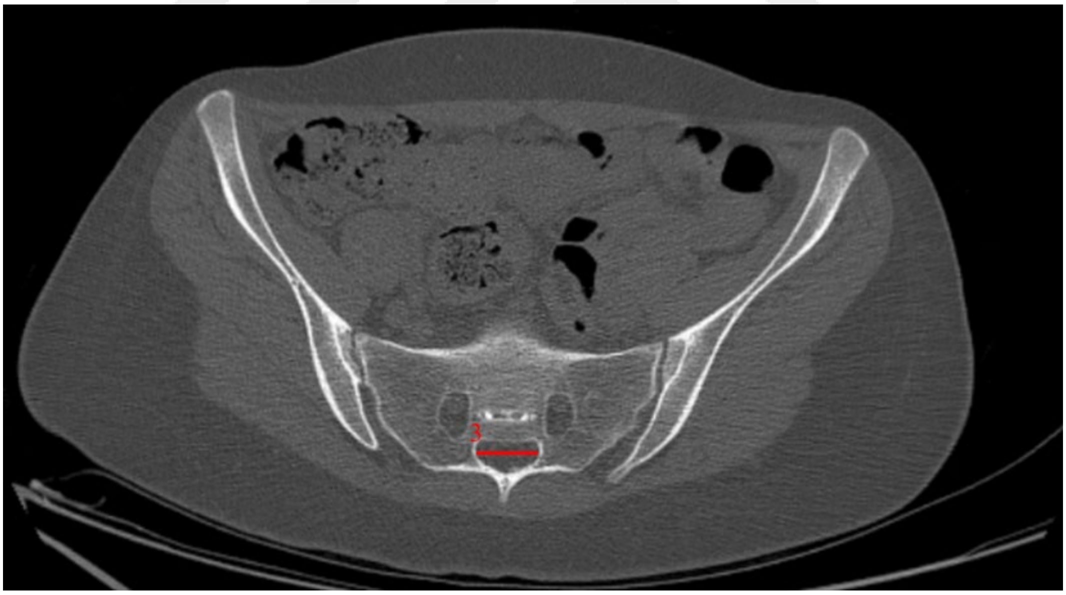

Figure 3.3. The measurements of width of the canalis sacralis (WCS). (Representation of the WCS variable in the RDv program of the image received from the PACS system in Dicom format)

Figure 3.5. The measurements of anterior sacral length (SL). (Representation of the SL variable in the RDv program of the image received from the PACS system in Dicom format)

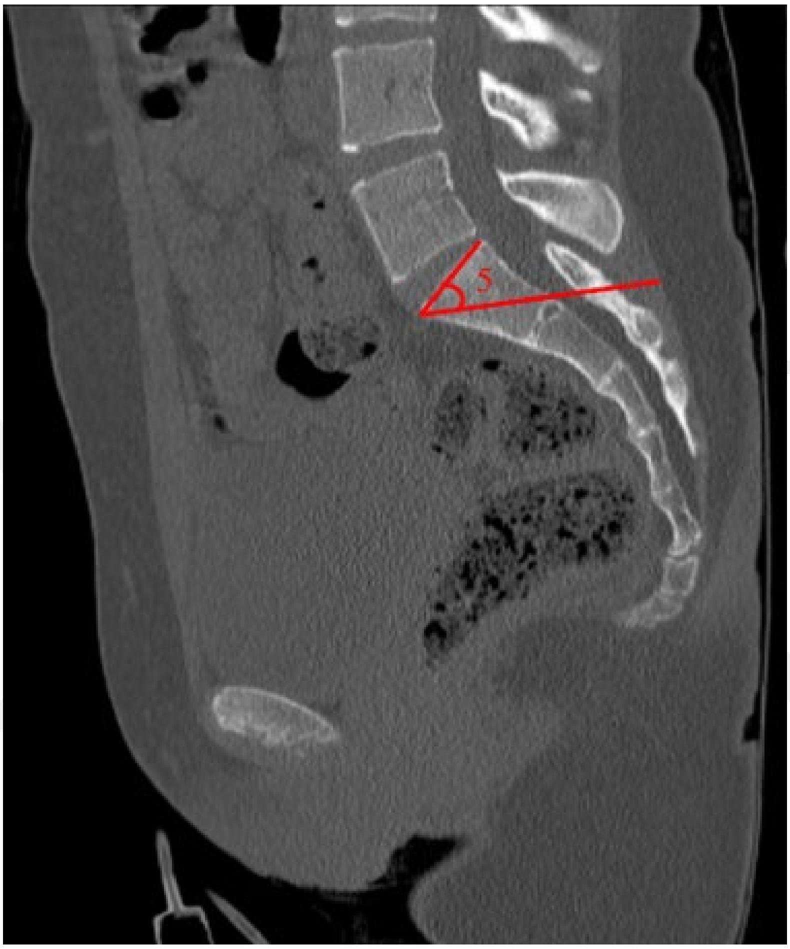

Figure 3.6. The measurements of sacral angles (SA). (Representation of the SA variable in the RDv program of the image received from the PACS system in Dicom format)

3.5 Formation of groups

The study consisted of 200 individuals (100 males, 100 females) divided into 5 groups. The groups have the following characteristics: first group, healthy individuals aged 16-19 years, second group, healthy individuals aged 20-29 years, third group, healthy individuals aged 30-39 years, fourth group, healthy individuals aged 40-49 years, and fifth group, healthy individuals aged 50-59 years (20). Images that did not meet the criteria were excluded; for example, pictures showing the sacrum under 16 and older than 59 years old, or pictures showing the sacrum fractured or distorted in shape.

3.6 Statistical analysis

Residuals from the two-factor analysis of variance have been tested for normal distribution using the Anderson-Darling test. Two-factor variance (TFV) analysis has been performed for parametric variables. Tukey post-hoc test has been applied for the variables with statistically significant differences between groups as a result of TFV. Two simple t-tests have been applied for parametric variables and the Mann-Whitney U test has been applied for nonparametric variables. The difference between groups of nonparametric variables has been tested with the Krusskal-Wallis test. Mann-Whitney U test has been applied as the intergroup difference test for the variables that were significant as a result of this test.

4. RESULTS

In the analysis, the two-factor analysis of variance has been applied to the variables. Then, the normal distribution of the residuals was tested with the Anderson-Darling test. The analysis revealed that age, SW, and SI variables have not been found to conform to the normal distribution, and transformation procedures were applied. Residuals of the SL variable were non-normally distributed and logarithmic transformation has been useful. Mean and 95% confidence intervals have been calculated for the SL variable. Mean and standard deviation (SD) values have been calculated for variables that fit the normal distribution, and median (med), minimum (min), and maximum (max) values have been calculated for variables that do not fit the normal distribution. The results of the analysis and descriptive statistics of the variables are shown in Table 4.1.

Table 4.1. Descriptive statistics results of variables

Variable	Gender	Group G1	G2	G3	G4	G5	p-value
Age	M (n=20)	18 (16-19)[a]	23 (20-29)[b]	36 (30-39)[c]	42 (40-48)[d]	55 (50-59)[e]	<0.001†
	F (n=20)	19 (16-19)[a]	25 (20-29)[b]	37 (30-39)[c]	46 (40-49)[d]	54 (50-59)[e]	
	p-value	0.064	0.495	0.245	0.005	0.513	
SA	M (n=20)	25.8±10.5	21.1±8.0	23.1±6.4	27.1±6.4	24.9±6.4	0.880≠
	F (n=20)	22.1±6.3	22.5±6.9	27.5±10.8	25.1±8.3	25.5±7.1	0.133*
	p-value	0.194	0.548	0.125	0.402	0.773	0.184**
ALCS	M (n=20)	0.8±0.3[a]	0.9±0.2[ab]	1.0±0.2[ab]	1.2±0.3[b]	1.0±0.3[ab]	0.560≠
	F (n=20)	1.0±0.2[ab]	1.0±0.2[ab]	1.0±0.16[ab]	1.0±0.2[ab]	1.1±0.4[ab]	0.011*
	p-value	0.125	0.371	0.562	0.085	0.406	0.119**
WCS	M (n=20)	2.5±0.32	2.4±0.2	2.5±0.2	2.4±0.4	2.4±0.2	<0.001≠
	F (n=20)	2.1±0.3	2.3±0.2	2.4±0.2	2.3±0.3	2.3±0.2	0.183*
	p-value	0.001	0.141	0.136	0.528	0.107	0.218**
SL	M (n=20)	10.8 (10.3-11.4)	11.1 (10.6-11.7)	11.4 (10.9-11.9)	10.8 (10.2-11.4)	10.7 (10.2-11.2)	0.025≠
	F (n=20)	10.6 (10.3-11.0)	10.7 (10.3-11.1)	10.9 (10.4-11.4)	10.5 (10.0-10.9)	10.6 (10.1- 11.1)	0.216*
	p-value	0.521	0.171	0.132	0.294	0.709	0.905**
SW	M (n=20)	11.2 (9.9-12.1)[a]	11.5 (9.4-12.5)[ab]	11.7 (10.49-12.3)[b]	11.5 (9.47-12.51)[b]	11.5 (10.3-14.2)[b]	0.018†
	F (n=20)	11.1 (10.0-12.7)[a]	11.6 (10.8-12.5)[ab]	12.0 (10.11-12.63)[b]	11.5 (2.88-13.53)[b]	11.7 (11.1-21.2)[b]	
	p-value	0.465	0.119	0.490	0.675	0.635	
SI	M (n=20)	105.7 (80.2-115.7)	100.8 (87.5-121.7)	104.8 (86.3-179.7)	107.5 (20-130.5)	107.1 (90.0-168.5)	0.120†
	F (n=20)	106.6 (89.8-125.5)	110.9 (96.4-124.6)	107.6 (92.6-132.7)	110.3 (27.0-132.5)	114.1 (87.4-188.2)	
	p-value	0.494	0.007	0.327	0.133	0.182	

† The p-value from the Krusskal-Wallis test. ≠ The p-value shows the difference between genders in the two-factor analysis of variance. * The p-value shows the difference between the groups in the two-factor analysis of variance. ** The p-value shows the difference between gender-group interactions in the two-factor analysis of variance.

The median value of age (in years) was 18 for males and 19 for females in the first group; 23 for males and 25 for females in the second group; 36 for males and 37 for females in the third group; 42 for males and 46 for females in the fourth group; 55 for males and 54 for females in the fifth group. Statistically significant age differences were found between the groups (p-value <0.001). The difference in terms of gender between the individuals forming each group was statistically significant in the fourth group while it is non-significant within the other groups. The boxplot graph for the age variable is shown in Figure 4.1.

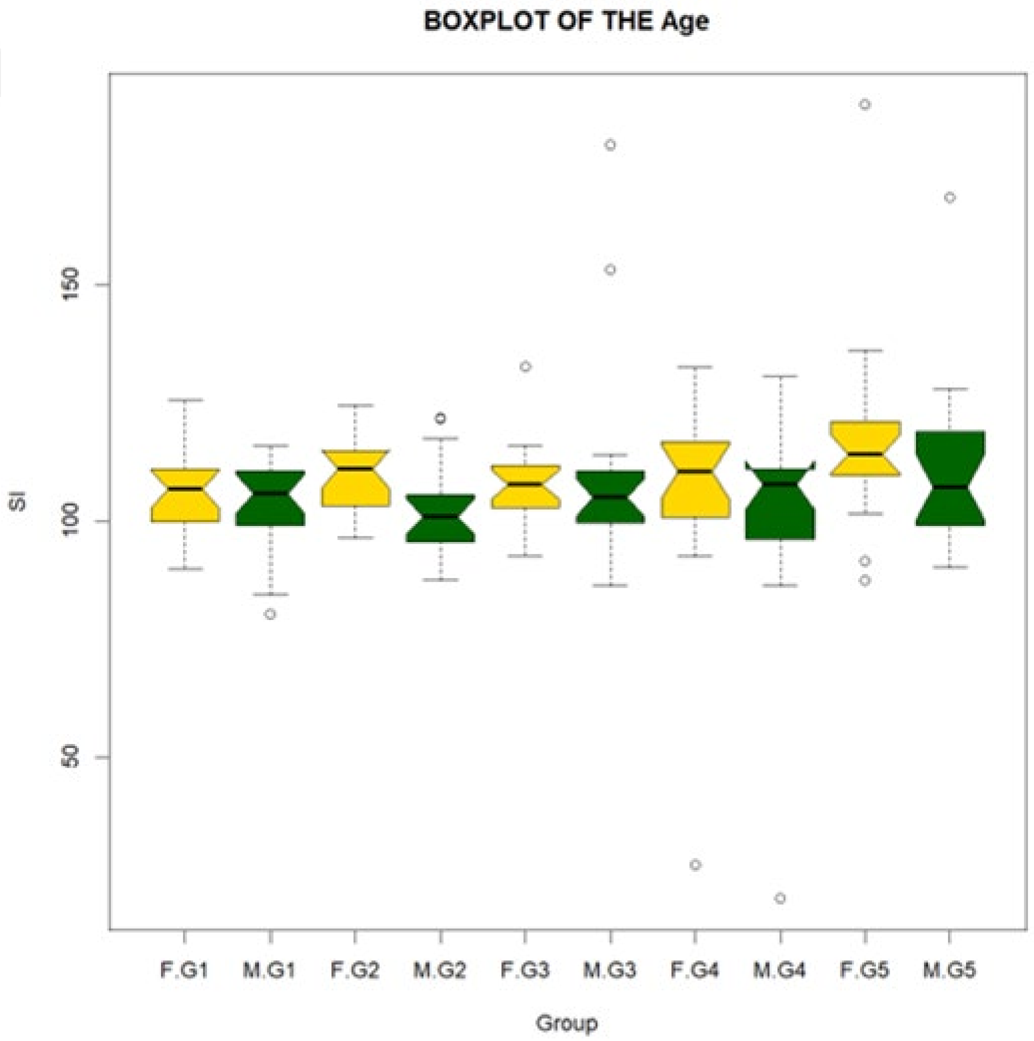

Figure 4.1. The boxplot graph for the Age variable

The mean value of the SA variable in degree has been determined as 25.8 for males and 22.1 for females in the first group; 21.1 for males and 22.5 for females in the second group; 23.1 for males and 27.5 for females in the third group; 27.1 for male and 25.1 for female in the fourth group; 24.9 for male and 25.5 for female in the fifth group. In the analyses performed to determine the difference between the groups and within each group based on gender, there were no statistically significant differences in the SA value between all groups and between the individuals forming each group. The boxplot graph for the SA variable is shown in Figure 4.2.

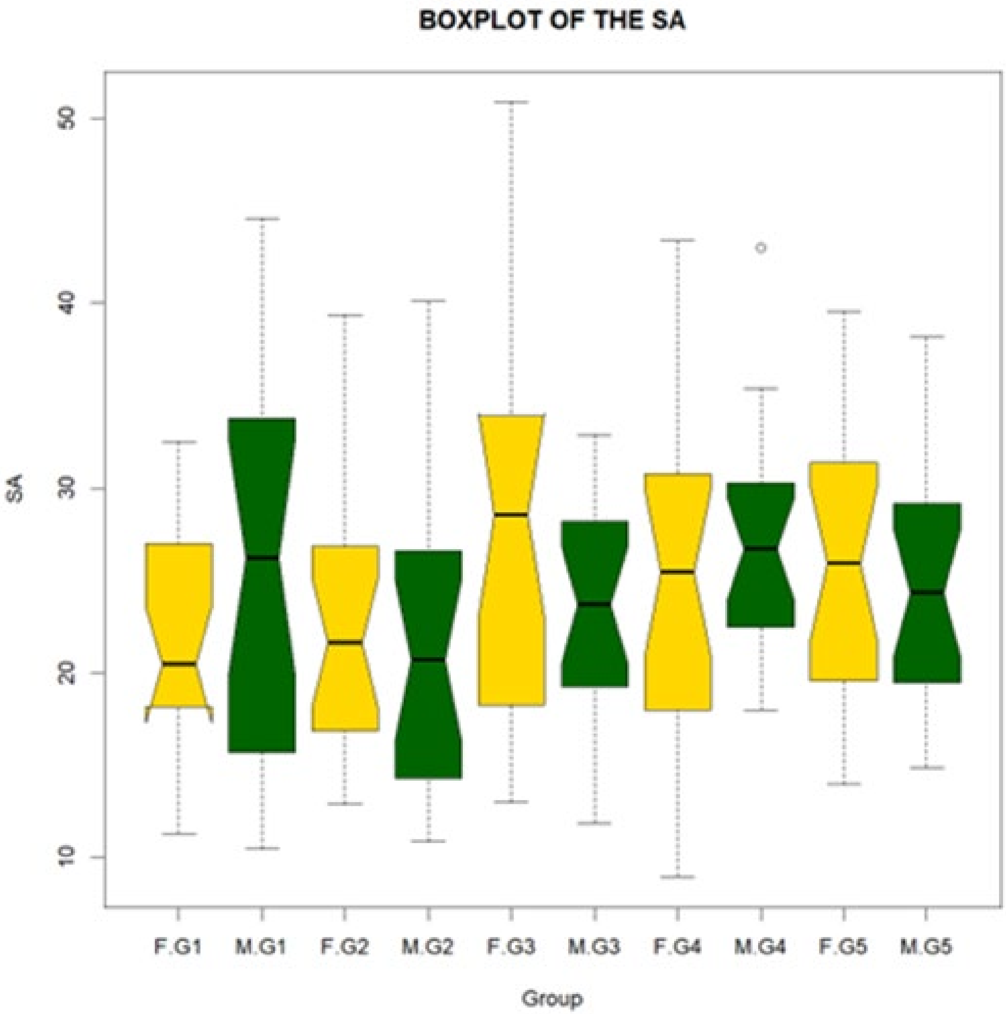

Figure 4.2. The boxplot graph for the SA variable

The mean value of the ADCS variable centimeter has been determined as 0.8 for males and 1.0 for females in the first group; 0.9 for males and 1.0 for females in the second group; 1.0 for males and 1.0 for females in the third group; 1.2 for male and 1.0 for female in the fourth group; and 1.0 for male and 1.1 for female in the fifth group. In the analyses conducted to determine the difference between the groups, the group difference has not been found statistically significant. No significant statistical difference in the ADCS value was observed based on gender within each group. The boxplot graph for the ADCS variable is shown in Figure 4.3.

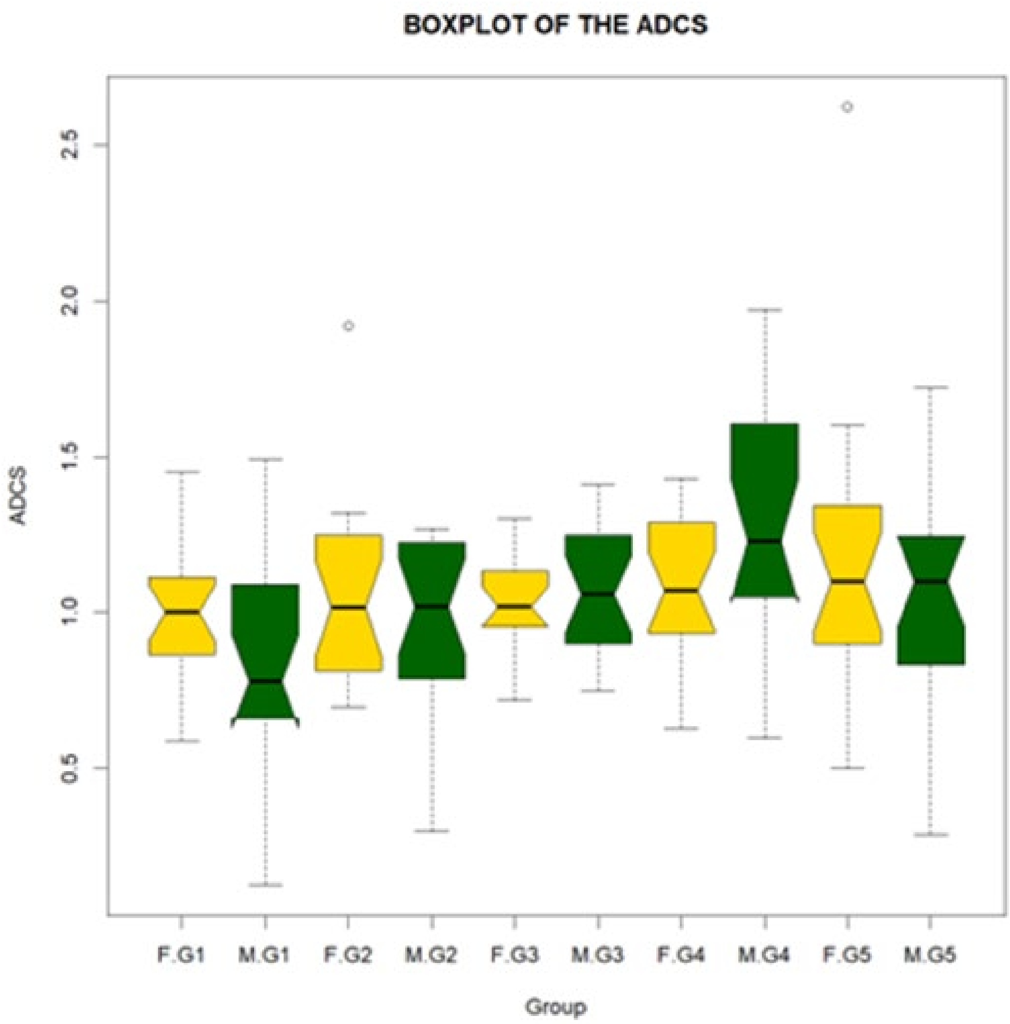

Figure 4.3. The boxplot graph for the ADCS variable

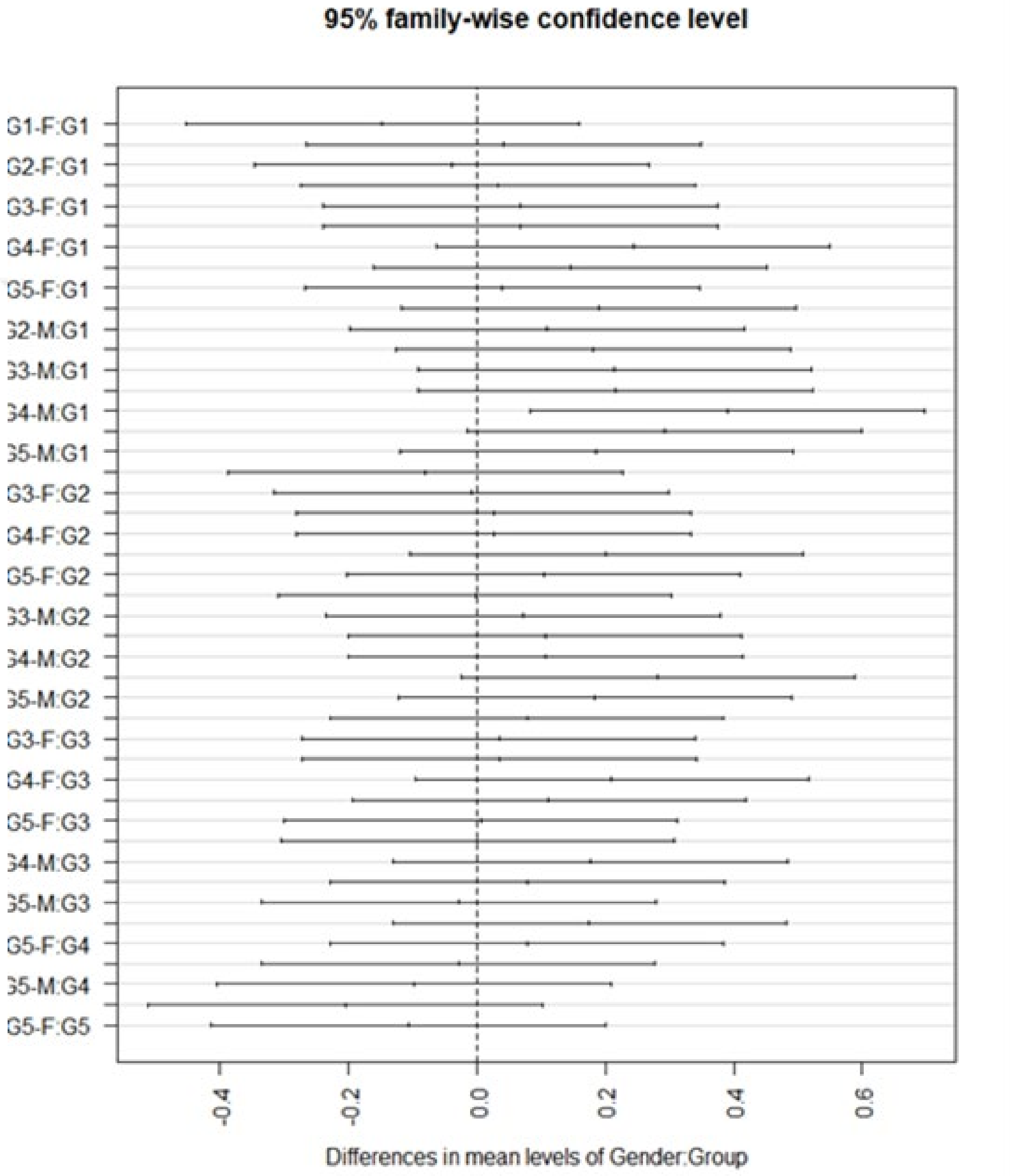

Figure 4.4. Graph showing Tukey result for ADCS variable

The mean value of the WCS variable in centimeters has been determined as 2.5 for males and 2.1 for females in the first group; 2.4 for males and 2.3 for females in the second group; 2.5 for males and 2.4 for females in the third group; 2.4 for males and 2.3 for females in the fourth group; and 2.4 for males and 2.3 for females in the fifth group. In the analyses performed to determine the difference between the groups, the difference between all groups has not been found statistically significant. The difference between the individuals of the first group in terms of gender has been found statistically significant (p-value <0.05) with a higher mean among males compared with females. However, the difference in terms of gender between the individuals forming the other groups was not statistically significant. The boxplot graph for the WCS variable is shown in Figure 4.5.

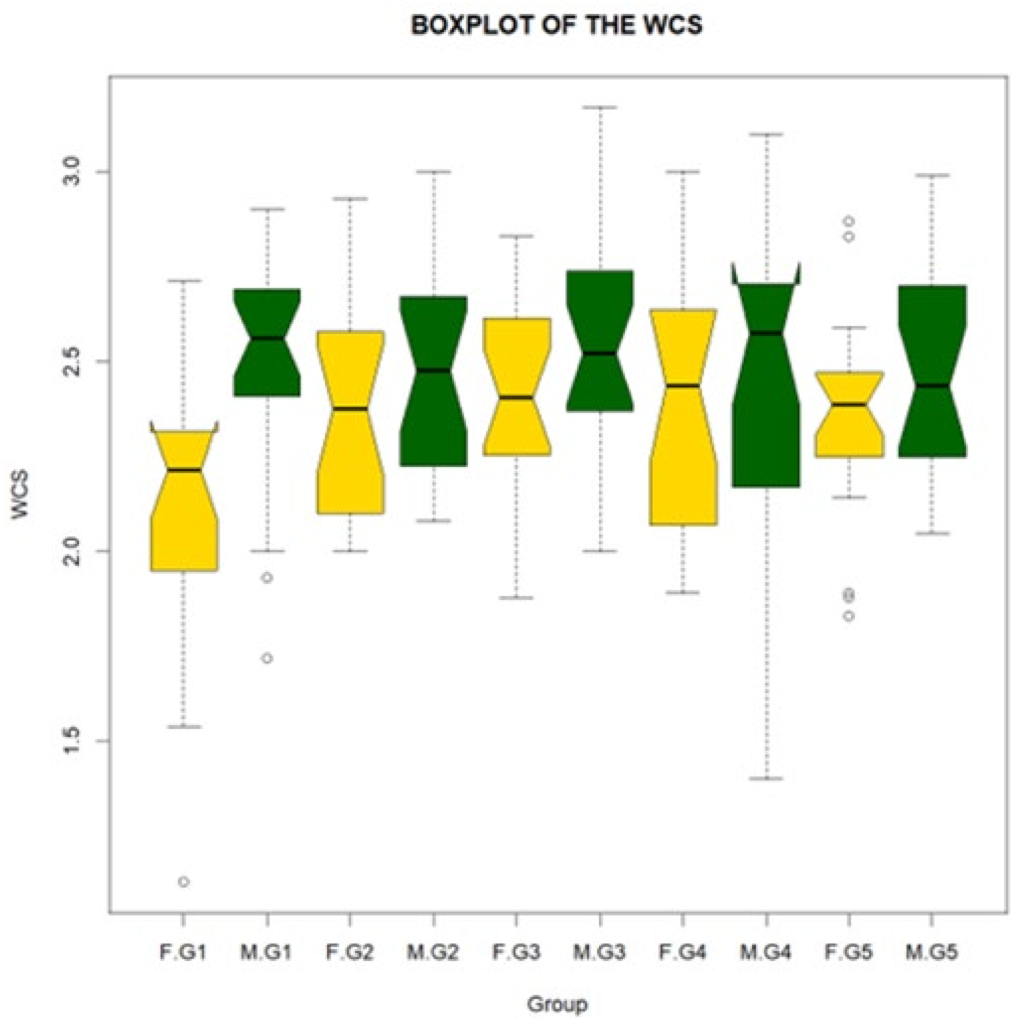

Figure 4.5. The boxplot graph for the WCS variable

The median value of the SL variable in centimeters has been determined as 10.8 for males and 10.6 for females in the first group; 11.1 for males and 10.7 for females in the second group; 11.4 for males and 10.9 for females in the third group; 10.8 for male and 10.5 for females in the fourth group; 10.7 for male and 10.6 for females in the fifth group. In the analyses performed to determine the difference between the groups, the difference between all groups is not statistically significant. The difference in terms of gender between the individuals forming each group is statistically insignificant for all groups. The boxplot graph for the SL variable is shown in Figure 4.6.

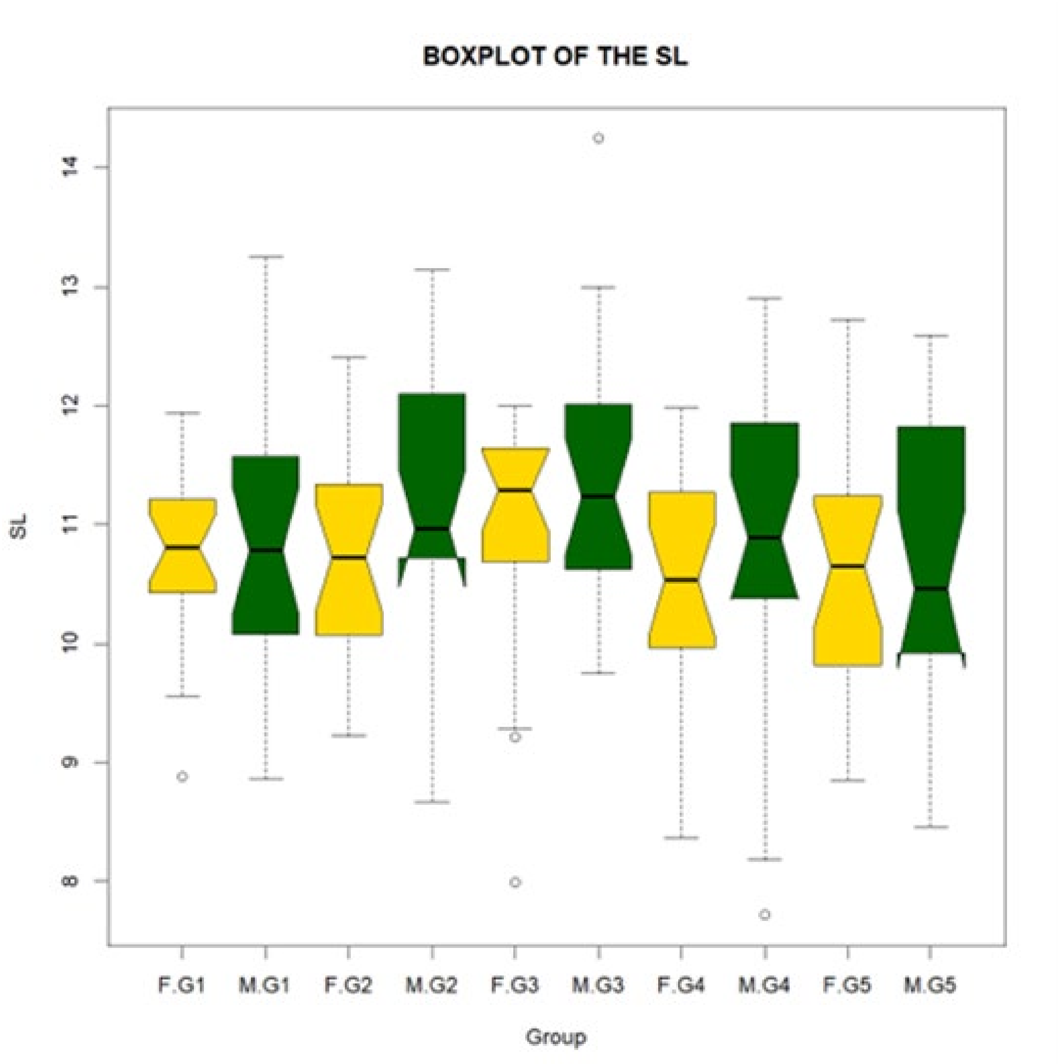

Figure 4.6. The boxplot graph for the SL variable

The median value of the SW variable in centimeters is 11.2 for males and 11.1 for females in the first group; 11.5 for males and 11.6 for females in the second group; 11.7 for males and 12.0 for females in the third group; 11.5 for males and 11.5 for females in the fourth group; and 11.5 for male and 11.7 for females in the fifth group. In the analyses performed to determine the difference between the groups, the difference between all groups was found to be statistically significant (p-value <0.05). The difference in terms of gender between the individuals forming each group is statistically insignificant within all groups. The boxplot graph for the SW variable is shown in Figure 4.7.

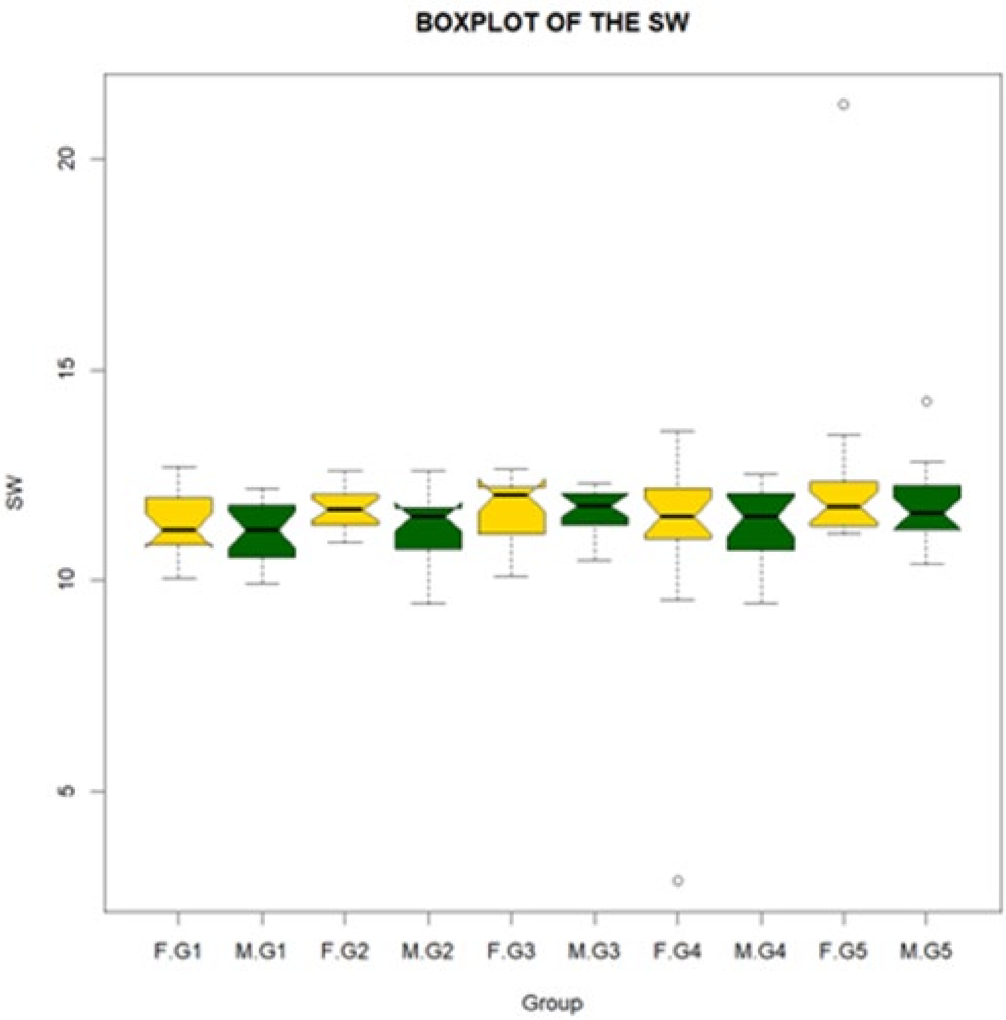

Figure 4.7. The boxplot graph for the SW variable

The median value of the SI variable in centimeters has been determined as 105.7 for males and 106.6 for females in the first group; 100.8 for males and 100.9 for females in the second group; 104.8 for males and 107.6 for females in the third group; 107.5 for male and 110.3 for females in the fourth group; 107.1 for males and 114.1 for females in the fifth group. In the analyses performed to determine the difference between the groups, the difference between all groups was non-statistically significant. The difference between the individuals of the second group in terms of gender has been found statistically significant with a higher SI median value among females compared with males (p-value <0.05). The difference in terms of gender between the individuals forming the other groups is not statistically significant The boxplot graph for the SI variable is shown in Figure 4.8.

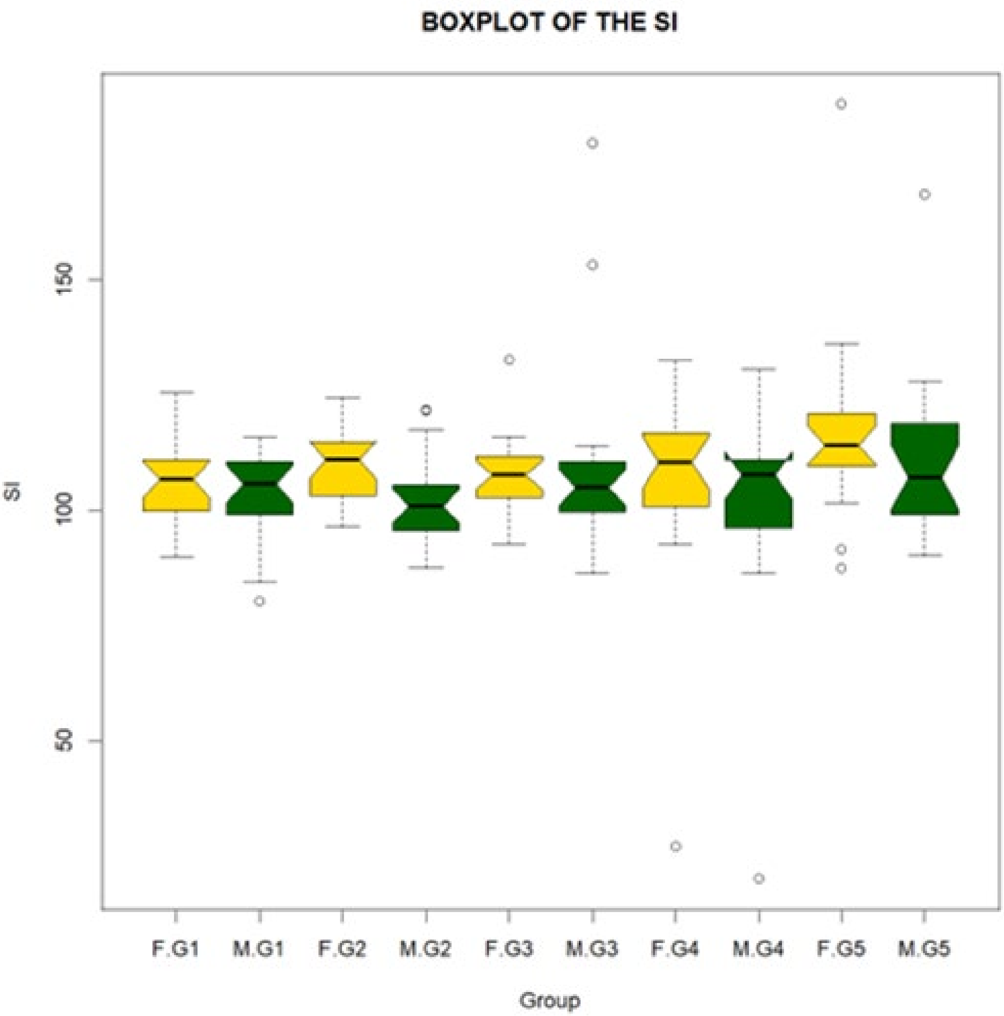

Figure 4.8. The boxplot graph for the SI variable

5. DISCUSSION

This study was designed to investigate the changes in the parameters of the sacrum, in relation to gender and age of 200 individuals (100 males, 100 females), aged 16-59 years, admitted to Bolu Abant İzzet Baysal University Training and Research Hospital in Turkey. The healthy individuals were divided into five groups; the first group aged 16-19 years, the second group aged 20-29 years, the third group aged 30-39 years, the fourth group aged 40-49 years, and the fifth group aged 50-59 years. The parameters that were measured in the study were sacral angles (SA), anterioposterior length of the sacral canal (ALCS), width of the sacral canal (WCS), sacral length (SL), sacral width (SW), and sacral index (SI). Overall, The results showed that there were no statistically significant variations in the SA, ADCS, and SL values among the groups and the individuals forming each group. On the other hand, the WCS parameter was not a statistically significant variable among the groups; however, the difference among the individuals in terms of gender was statistically significant in the first group (p-value <0.05), but not in the other groups. Moreover, the SW parameter was significantly variable among the groups, but there was no significant variation among the individuals of the same group. Finally, SI was significantly variable based on the gender in group 2, however, it was not significantly different within the individuals of other groups and between the groups.

The sacrum is considered a key bone in maintaining hip stability because it connects the spine with the iliac bones. Several studies were carried out and revealed numerous variations in the skeleton including the sacrum. The observed variation in some variables determining the geometry of the bony pelvis differs significantly between males and females could be explained as a demand of the physiological differences. Moreover, knowledge of anatomical variations is very important in the clinical field and for medical education. As far as the literature has been evaluated, it has been observed that there are several studies on the sacrum as a dry bone. A previous study conducted in India on 254 sacral bones (190 males and 64 females) for gender determination from skeletal remains revealed that the ventral straight of the SL and the ALCS of sacral vertebra were significantly greater in males than females, while the SI was significantly greater in females than males. In addition, the SI was reported as the most useful index for sex determination (21). In line with the current study outcomes, a previous study conducted in Turkey showed that gender could be estimated from the measurements of sacral bones (22). The variables SL, SW, and WCS of the sacral vertebra were measured in 91 dry human sacral bones (45 males and 46 females), but no significant differences were observed in the studied variables based on gender. Consistent with the current study outcomes, an earlier study conducted on 110 dry human sacrum bones from the Indian population (68 males and 42 females) revealed that gender could be estimated from measurements of sacral bones. At the end of the study, gender differences in SL was significantly higher in males than females, whereas the SI was significantly higher in female sacra in comparison to male sacra. In addition, gender differences in the SW and WCS variables were found to be significantly higher in females (23).

Several studies also found that the LS was significantly greater in males than in females, but the difference was not significant for the SW (24, 26). There was a statistically significant difference in the mean SI, which was reported to be greater in females than in males. In a previous study for gender determination from sacral bone measurements, the variables SL, SW, SI, the ALCS, and WCS were measured in 140 dry human sacral bones (83 males and 57 females), and it was shown that all of the above-mentioned variables, except SW, were significantly different between males and females (25). Similarly, a study from India reported significant differences in sacral variables based on gender (27). The mean value of the SW and SI were higher in females, while the mean value of the SL was higher in males than females. The above-mentioned morphometric parameters of the sacrum are of great importance in the determination of sex, especially in forensic cases when the skull and pelvis are fragmented or unavailable.

Additionally, another study in India estimated gender from measurements of the sacrum bone (28). The SL, SW, and SI variables of the sacrum were measured in 116 dry bones (42 females, 74 males). At the end of the study, gender differences in SL and SI variables were found to be significant, while SW was non-significant. Another study on dry bones was performed on 100 fully ossified adult sacrum (42 females, 58 males). In the study, gender differences in SL and WCS variables were found to be significant, while the SW variable was not significant (29). Similar results were encountered in a study conducted on the sacrum bones of 58 individuals (31 females, 27 males) to evaluate the effectiveness of the sacrum in differentiating males from females. The variables of SW and WCS were found to be significantly higher in males than in females (30). Variable outcomes from different studies from different studies could be explained by the variation in the study methods and measurement tools. Moreover, genetic, hormonal, and environmental factors could play an important role in skeletal development including the sacrum.

According to a study conducted on 230 bones (115 females, 115 males) in Southern India, SL, SW, and SI variables were measured using the vernier caliper and there were significant variations in the studied parameters based on gender. The SW was higher in males while SI was higher in females (31). Similarly, in a study of 43 dry sacrum bones (22 females, 21 males) in Oman, gender was estimated from measurements of the SL, SW, ALCS, and WCS, and gender differences in these variables were found to be significant (32).

Studies on the sacrum are not limited to dry bone. In one study, measurements have been made both on CT images and with calipers to evaluate the variation of the sacrum according to gender. The metric measurements on CT images have been shown to be very accurate and comparable to caliper measurements on real bones for gender determination, but CT should be used in combination with other methods (33). In another study using CT images, gender among the Egyptian population has been estimated from measurements of the sacrum and coccyx bones (4). The SL variables of the sacrum were measured in 230 individuals (115 females, 115 males) aged 18-77 years, and in accordance with the present study outcomes, gender differences in these variables were found to be statistically significant. Similarly, according to a study conducted on 480 individuals living in Germany, gender and age have been estimated from measurements of the sacrum and coccyx bones (34). The variables; SL, SI, ALCS WCS, and SA varied significantly between males and females while the SW was not significantly different. A similar result has been found in a study conducted using CT on 350 living individuals (190 males and 160 females) in China, where SL and ALCS were found to be significantly higher in males, while SW was significantly higher in females. The study also showed that prediction equations based on skeletal variables in different populations can be influenced by genetic and environmental components and that different equations should be developed according to studies applied in living populations. In conclusion, the sacrum and coccyx can be considered substantial bones for gender determination and may be useful in forensic cases when the skull and pelvis are not available (35).

In addition to the importance of the documented variation in the geometry of the sacrum in the current study and previous studies in sex determination and its importance in forensic science and the clinical field. The observed significant variation in some variables determining the geometry of the bony pelvis including the sacrum between males and females could be explained as a demand of the physiological differences. The obstetric demands in females explain these variations. Females have a relatively larger and rounder pelvic cavity, a shorter and more posteriorly projecting sacrum, a wider subpubic angle, and a smaller acetabulum with a larger distance between them. The female sacrum can also be observed as being shorter than the sacrum of a male. The difference in width can be explained by the overall wider shape of the female pelvis. The female sacrum is also more curved posteriorly. This could be explained by the need for as much space as possible for a birthing canal. As part of the pelvis bones and being an attachment of several muscles, the sacrum features in males could be of great importance as an adaptation of the greater body mass of males.

6. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the current study provides indications that the sacrum is a necessary bone for gender determination,which might be efficiently used in forensic science.

SI, WCS, SL, ADCS and SW of the sacrum are of great importance and could be significantly variable based on gender and age.

However, further studies regarding gender determination from sacrum should be considered in different populations due to the fact that genetic and environmental factors could influence the skeletal system development, thus, sacrum parameters could be different in different ethnicities.

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