Sex Assessment of the First Sacral Vertebra, MRI Study

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Abstract: Determination of sex from the skeletal remains is of vital medico-legal importance for establishing the identity of an individual. **Aims:** To study the sexual differences in the first sacral vertebra (S1) in middle-aged adults through devising new parameters and indices. **Material and Methods:** 100 mid-sagittal MR images of lumbosacral region (50 males and 50 females) were investigated. The dimensions of S1 as well as inclination angles of sacrum were measured and statistically analyzed. **Results:** Male S1 showed higher values than that of female S1 in all of the investigated parameters, except for LSA. The parameters showed sex differences of variable levels. Also, Index 1(ID/SD×100) and Index 2 (PH/AH×100) showed significant sex differences. Application of univariate ANOVA revealed an accuracy in assigning sex of S1 for 95% of the cases, with accurate predictions being made for 97.5% of females and 92.5% of males. **Conclusion:** The body of the first sacral vertebra (S1) is a good bone for sex determination. The newly devised MRI parameters of S1 might be used to aid in identification of human skeletal and fleshed remains.

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1. Introduction

It has long been customary among anatomists, anthropologists and forensic experts to judge the sex of the skeletal material by non-metric observations. Lately, sexual divergence has been based upon morphometric analysis of the bones [(1)]. Such determination is an important parameter for the anthropological examination and identification of skeletal remains [(2)]. Procedures are usually based on the analysis of sexually dimorphic cranial and pelvic traits [(3)]. The pelvis is the most sexually dimorphic area of the adult human skeleton [(4)]. Studies in the metric characteristics of male and female sacra has seemed to be less numerous than that for the rest of the pelvis [(1)]. The reports concerning results and accuracies also seem to be quite different, with some authors noticing it usable and others less so [(1,5-7)]. The curvature of the sacrum has been investigated for identification of sex in many studies [(3,8-10)]. The sacrum is more curved in men than in women [(2)]. Reduced sacral curvature, along with posterior angulation of the sacrum, serves to enlarge the female pelvic outlet for childbirth [(11)]. Therefore, the posterior angulation of the sacrum might be a reliable indicator of sex. Little attention has been paid to this anatomic issue. To our knowledge, there are no published data involving MRI study of first sacral vertebra for identification of sex. MR imaging represents a feasible, reproducible and accurate method for evaluating the normal vertebral body dimensions because of the high contrast resolution. Also, it eliminates measurement limitations of conventional radiographs, such as variability in the film–focus distance, rotation of the spine and parallax effect [(12)]. The exact assessment of the sacral parameters might be difficult, using dry bones. The purpose of this study was therefore to develop new devised MRI measurements for the first sacral vertebra which can be used for sex determination of skeletal remains.

2. Material and Methods

MRI of the lumbosacral region of adults were studied. The images were obtained for various reasons such as soft tissue injuries, muscle pain and low back pain. The images were excluded if pathology affecting the anatomy of the vertebrae and inter-vertebral discs was present. They were explored in the radio-diagnostic department, Majmaah, King Khalid Hospital, KSA, during the period "February 2011 to April 2013". MR images of the lumbo-sacral region were examined to get the appropriate view of the first sacral vertebra (S1). Total number of 100 normal images was incorporated in the study. Measurements were performed in mid-sagittal plane. The following metric data from body of the first sacral vertebra (S1) were collected: anterior height (AH), posterior height (PH), superior mid-sagittal diameter (SD) and inferior mid-sagittal diameter (ID). All measurements were taken to the nearest millimeter (mm). Additionally, the following angles were measured: the sacral base angle (SBA), lumbo-sacral angle (LSA) and anterosuperior angle (ASA) of S1 (Table 1, Figure 1).

Each variable was measured three times at different times. Additionally, two indices using ID, SD, PH and AH were calculated. The following formulae were used for these indices:

- Index 1: ID/SD×100
- Index 2: PH/AH×100

The mean age of individuals was calculated. Then, the obtained data of the S1 were scrutinized, tabulated and statistically analyzed, using maximum and minimum values, range, mean, standard deviation and 95% confidence intervals of mean. The existence of significant differences between the means for the two subsamples was analyzed by using independent Student's *t*-test. A *P*-value <0.05 was considered to be statistically significant. Data on S1 were further subjected to discriminant function analysis using univariate ANOVA to determine which variable provided the best discrimination between the sexes.

3. Results

There were 50 males with a mean age of 35 years (range 29-41 years) and 50 females with a mean age of 32 years (range 26-38 years). The sacrum was seen to be more curved in males than in females. Meanwhile, the female sacrum was noticed to be more horizontally positioned in comparison to the male sacrum (Figure 1).

Repeated measurements were very similar. The investigated data are summarized in table 2. The metric data differed between the sexes for the S1 variables. On average, all dimensions were larger in males than in females (Figure 2). The differences were statistically significant in the investigated dimensions. The index 1 (ID/SD×100) of females was smaller (mean: 72.10±6.96) than that of males (mean: 76.38±7.54) (Table 2). Also, the index 2 (PH/AH×100) showed the same trend but with a larger range of differences (10.50 on average). The values of the investigated angles also differed between males and females. Whereas the differences between males and females in regard to ASA were considered to be not statistically significant (*P*-value=0.3859), the sex differences in LSA and SBA were statistically significant (*P*-value <0.0001 and =0.1515 respectively) (Table 2, Figure 3). Univariate ANOVA revealed that the male and female S1 differed significantly on each of the predictor variables. A single discriminant function was calculated. The value of this function was significantly different for females and males (*P*-value <0.0001). The correlations between predictor variables and the discriminant function suggested that AH (r=91.7%), LSA (r=70.6%), SD (r=-86.2%) and ASA (r=-50.4%) were the best predictors. Overall the discriminant function successfully predicted outcome for 95% of the cases, with accurate predictions being made for 97.5% of females and 92.5% of males.

Table (1) Definitions of anatomic parameters of the body of the first sacral vertebra (S1)

	Parameter	Abbreviation	Definition
1	Anterior height	AH	The maximum distance between superior and inferior limits of the anterior border of S1 vertebral body at the mid-sagittal plane.
2	Posterior height	PH	The maximum distance between superior and inferior limits of the posterior border of S1 vertebral body at the mid-sagittal plane.
3	Superior diameter	SD	The maximum distance from anterior to posterior limits of the superior border of S1 vertebral body at the mid-sagittal plane.
4	Inferior diameter	ID	The maximum distance from anterior to posterior limits of the inferior border of S1 vertebral body at the mid-sagittal plane.
5	Sacral base angle	SBA	The angle between the superior border of S1 vertebral body and the horizontal line.
6	Lumbosacral angle	LSA	The angle between the anterior border of S1 vertebral body and that of the 5th lumbar vertebra.
7	Anterior sacral angle	ASA	The angle between the superior and anterior borders of S1 vertebral body.

Table (2) Statistical analysis of the investigated measurements and indices in males and females

	Males (No. 50)			Females (No. 50)			MGD	SE	95% CI	*P*-value
	Mean	±SD	Range	Mean	±SD	Range				
AH (mm)	33.805	±2.943	26.6-39.7	32.585	±1.865	28.7-35.7	1.220	0.551	0.123 to 2.317	=0.0297
PH (mm)	25.813	±2.817	20.9-29.7	23.533	±1.812	19-28.5	2.280	0.530	1.226 to 3.334	<0.0001
SD (mm)	34.465	±2.664	30-42.9	31.245	±2.071	28-35	3.220	0.534	2.158 to 4.282	<0.0001
ID (mm)	22.202	±2.526	18.7-29.2	16.898	±1.971	13.7-21.1	5.305	0.507	4.296 to 6.314	<0.0001
Index 1 (PH/AH×100)	76.38	±7.54	56-92	72.10	±6.96	64-97	4.28	1.623	1.04 to 7.51	=0.0102
Index 2 (ID/SD×100)	64.55	±5.82	41-69	54.05	±6.97	54-80	10.50	1.436	7.64 to 13.36	<0.0001
SBA (º)	40.97	±6.92	30-53	38.72	±5.85	28-56	2.25	1.548	-0.84 to 5.34	=0.1515
LSA (º)	49.670	±5.630	53-73	63.948	±4.151	40-60	-14.278	1.106	-16.479 to -12.076	<0.0001
ASA (º)	39.60	±7.06	30-48	38.38	±5.40	28-53	1.23	1.405	-1.57 to 4.02	= 0.3859

SD=Standard deviation, MGD=Difference between mean of two groups, CI=Confidence interval, SE=Standard error of difference

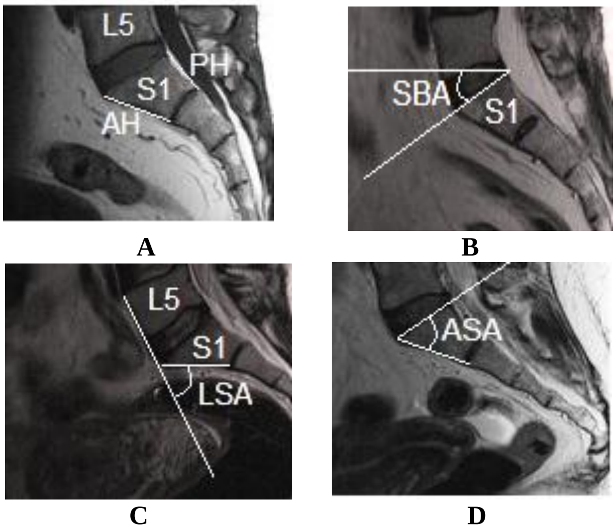

Figure (1) Mid-sagittal MRI identifying: A) Anterior height (the white line at AH) and the posterior height (the white line at PH) of the body of the first sacral vertebra (S1) in an adult male, B) Sacral base angle (SBA) in an adult male, C) Lumbosacral angle (LSA) in an adult female, D) Anterior superior angle (ASA) in an adult female, L5=fifth lumbar vertebra.

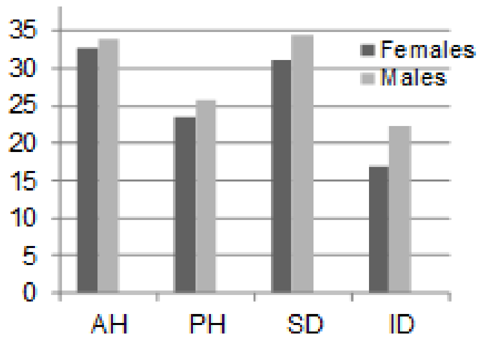

Figure (2) A histogram showing the mean measurements of the first sacral vertebra (S1)

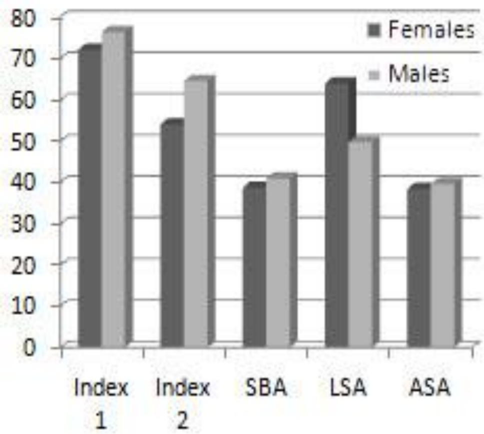

Figure (3) A histogram showing the mean data of the indices and angles at first sacral vertebra (S1)

4. Discussion

The sacrum is a key component in the human body, so it deserves its name: sacred/holy bone [13]. It is a part of the vertebral column, forming the base on which the rest of the column is erected. Therefore, its dimensions and position dictate much of the vertebral column's form, shape, and stability [14]. On the other hand, it is a part of the pelvic girdle, reflecting its sexual dimorphism [15]. Metric estimation of sex from the pelvic bones becomes particularly important when dealing with incomplete or fragmented remains, or cases where the morphology is ambiguous [16]. At the same time, some measurements in the pelvis may be very difficult to record accurately [17]. Therefore, in this study MR images were used for measurements of S1 body in order to obtain precise data at the mid-sagittal plane. Such mid-sagittal investigations might be useful specifically in identification of the fragmented or incomplete parts. Several studies have demonstrated that measuring the sacral base of anthropological collections can meet an accuracy of 80–90% in correct sex determination [3,5,8]. All authors measured the maximum transverse diameter, maximum anterior–posterior diameter, and perimeter of S1. In these studies, the maximum transverse diameter of S1 was the most suitable variable for sex determination. The ratio of S1 corpus' width to sacral width was lower in females compared with males [18]. In modern Greeks, dimensions of the sacrum, including its anterior length, anterior straight breadth and maximum breadth S1 were not very dimorphic [4]. Snell [18] reported that sacrum of females is usually wider in proportion to its length than that of males. In the present study, another metric data were gained from mid-sagittal MRIs of the sacra. The S1 was shown to be sexually dimorphic in all of the investigated dimensions and indices. On contrary to this finding, Plochocki [2] and Başaloğlu *et al.* [19], stated that there is no significant gender difference for the sacral height despite greater curvature in men. Başaloğlu *et al.* [19], in their study on dry bones, reported a slight difference ($P > 0.05$) in SD measurements between males (mean: 32mm) and females (mean: 30mm). This small difference is consistent with that recorded in the present study, but our measurements were slightly larger (mean in males: 34mm; mean in females; 31mm). The difference in values between these 2 studies might be attributed to the method used in measurements. In the current study, the anteroposterior diameters (SD and ID) of the body of S1 were seen to be larger in males than in females. These findings are similar to that of Mishra *et al.* [1], and Flander [5] who demonstrated that the body of S1 is significantly wider in males than in females. In an attempt to avoid magnification errors of imaging, we converted the metric data of S1 into ratios (or indices). This method standardizes the measurements, irrespective of the magnification power. It also gives a formula for the researcher to estimate measurement of one border even it is broken, from the measurement of the other intact one. Out of the investigated parameters of the sacrum, two mean parameters yielded extremely significant differences between the two sexes (*P*-value: <0.0001) with a great difference in the mean between the two groups. These were LSA (the mean difference between the 2 groups: -14.278) and index 2 (the mean difference between the 2 groups: 10.50). Univariate ANOVA suggested that AH (r=91.7%), LSA (r=70.6%), SD (r=-86.2%) and ASA (r=-50.4%) were the best predictors.

The shape of spinal curvatures is a particular feature of man. Lordosis of the lumbar spines ranged from 26.0º to 40.0º [20]. It has been evidenced that there is a close relationship between lumbar lordosis and pelvic angles [21,22]. Therefore, the degree of LSA might be affected by that of lumbar lordosis. The mean LSA in the current study was 49.670±5.630º in males and 63.948±4.151º in females. At the same time, ASA was detected to be lesser in females than in males. The increases in the LSA and decreases in the ASA in females reflect the more posterior sacral inclination and hence the wider pelvis in females than in males, noticed in other studies [11,23]. The posterior angulation of the sacrum serves to enlarge the female pelvic outlet for childbirth [11]. Regarding the SBA, there was no statistically significant gender difference (mean:40.97±6.92º in males and 38.72±5.85º in females). Similar values were previously reported by Hellems and Keats [24] (mean: 41.1º, named it: the lumbosacral angle) and Marty *et al.* [25], (mean: 40.59º, named it: the angle of sacral slope). The authors did not investigate the gender differences in the angle. In summary, the magnitude of sexual dimorphism in the investigated indices and lumbosacral and anterior sacral angles at S1 ranks these measures among the most highly dimorphic of the pelvis. However, for the determination of sex of sacrum, maximum number of parameters should be taken to attain 100% accuracy. The choice of these parameters must depend on the condition of the bone. Also, it will be influenced to some extent by the race from which the sample is drawn [5].

Conclusion

This study indicated that the body of the first sacral vertebra (S1) is a good bone for sex assessment. Moreover, it devised new formulae and parameters of S1 sex determination that can be used to aid in identification of human remains, utilizing MRI technology. Such a technique can be of value in both skeletal and fleshed remains.

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