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Sacroiliac Joint Bridging: Simple and Reliable Criteria for Sexing the Skeleton

ABSTRACT: Vital to the study of past populations and an important phase in executing a forensic anthropological examination is the determination of skeleton sex. The aim of this study is to present an easy and reliable criterion for sexing the skeleton. The ilium and sacrum of 2845 skeletons were examined for new bone formation and for bridging/fusion in/across the sacroiliac joint. Sacroiliac joint bridging (SIB) was present in 12.27% of the males and 1.83% of the females. In 97% of the males bridging was extra-articular, whereas in all females bridging was intra-articular. In addition, computed tomograghy images of 81 *in vivo* individuals were examined for the same phenomenon. SIB was present in 34.2% of the males and 4.6% of the females. Bony spurs present on the ilium for a preliminary partial or full extra-articular bridging of the sacroiliac joint indicate a male skeleton. SIB presents an easy technique for sexing skeletons (especially in elderly individuals where the phenomenon of SIB becomes very common), as no prior knowledge, training, or equipment is required to apply the criterion.

KEYWORDS: forensic science, forensic anthropology, sacroiliac joint, ankylosing, sexing skeleton

Properly determining skeleton sex is a key element in any anthropological study or forensic examination. Traditionally, sex determination of a skeleton is based on two main approaches: comment and description of the morphology of the bones, and values obtained using morphometry, in other words, bone measurements (1–8). The main techniques used to determine the sex of an unknown skeleton are based on dimorphism of two main regions in the body: the pelvis and the skull (1,8). Disparity in the size and shape of the sciatic notch and subpubic region are measured in the pelvis (1,4) and differences of the mastoid process size, protuberance of the glabella and supracilliary area, and frontal bone inclination are measured in the skull (1,2,5,7). Contributing factors for successful identification of sex are the rate of sexual dimorphism within the population, the age of the individual, and the preservation state of the bones.

This is why a highly reliable and valid criterion for sexing the skeletons can significantly contribute to all fields of physical anthropology. The present study examined the hypothesis that sacroiliac joint bridging (SIB) is strongly associated with sex and therefore can be used as a reliable criterion for assessing sex from the skeleton.

Methods

Macroscopic examination was performed on 2845 sacroiliac joints of complete skeletons from the Hamman-Todd Human (HTH) Osteological Collection of the Cleveland Museum of Natural History. These individuals died during the first half of the 20th century, with age at death, sex, ethnic origin, and cause of death documented for each individual. The collection consisted of 1518 Caucasian males, 837 African American males, 216 Caucasian females, 272 African American females, and two females of Asian descent.

The ilium and sacrum of each skeleton were examined for the presence of new bone formation and bridging/fusion in/across the anterior part of the joint. Full and/or partial bridging between the sacrum and the ilium was recorded as well as the beginning of new bone formation over (extra-articular) the sacroiliac joint (Figs. 1 and 2). The extent and location of the bridging was determined based on divisions into six areas of the anterior margin of the sacroiliac joint, as demonstrated in Fig. 3.

Differentiation between extra- and intra-articular ankylosis (9) was carried out, based on the following four parameters: Morphology—the extra-articular bridging (EAB) has a dome-shaped appearance and rugged surface, contrasted with smooth continuous fusion between the ilium and the sacrum bone in intra-articular cases (IAB) (Fig. 4). Total fusion (no remnants of the joint margin anteriorly) characterizes IAB (Fig. 4) and is rare in EAB. In EAB, the bony tongue that bridges the joint always runs from the ilium to the sacrum, whereas in IAB no direction of the bridging can be identified. Direct observation—in the majority of the cases, the bony bridge was broken and the innominates were separated from the sacrum (to allow the pelvis to fit into the drawers), allowing direct inspection of the articular surface. Radiographs—although of limited accuracy—were used in suspected cases (Fig. 5). Computed tomography (CT)—using multiplanar reformation technique—allows direct inspection of the joint cavity (Fig. 6).

The sacroiliac joint status of 81 *in vivo* individuals (38 males and 43 females) was examined using three-dimensional (3D) images of the pelvis (Fig. 6). The CT scanning (Model: Phillips Brilliance 64, Haifa, Israel; Thickness of sections: 1–2 mm; MAS: 80–250) was originally performed on people who arrived for abdomen or pelvis examination at the Radiology Department, Carmel Medical Center, Haifa, Israel.

The volume rendering method was used to obtain 3D images of the pelvises, as this application is the fast and easy way to visualize 3D structures using acquired CT. The method examines the intensity of the object; by assigning a color map depending on intensity values, one can easily separate between the various tis-

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FIG. 1—*Bilateral sacroiliac joint bridging: the fact that the joint area is the "watershed" between the sacrum and ilium (both manifest concave topography) gives the bridge a dome-shaped appearance.*

sues. The volume rendering is carried out by acquiring a set of volumetric data (in our case a sequence of parallel images) and assigning opacity and colors to every voxel according to user-defined parameters.

For intratest reliability, 10 pelvises and 10 CT images were reexamined for bridging (positive/negative) three times (a week interval from one test to another) by G. D. For intertest reliability, the above cases were examined by an independent investigator.

To assess the relationship of demographic parameters (sex, ethnic origin, age) with SIB, a χ^2 test was performed. Significance of difference was set at $p < 0.05$. To assess the age factor in SIB, the sample was divided into two age groups, above and below 60 years of age, and a χ^2 test was performed.

Results

The results are summarized in Tables 1 and 2.

Frequency

SIB was present in 289 males out of 2355 males in the HTH collection (12.27%), aged 18–105, and in nine out of 490 females (1.83%), aged 36–84 ($\chi^2 = 47.09$, df = 1, $p < 0.0001$). In the CT study, SIB was present in 13 males (34.2%) contrasted with only two females (4.6%) ($\chi^2 = 11.68$, df = 1, $p = 0.0006$).

Morphological Characteristic

Among males, the bridge characteristically has a slightly dome-shaped appearance (the highest point positioned over the joint

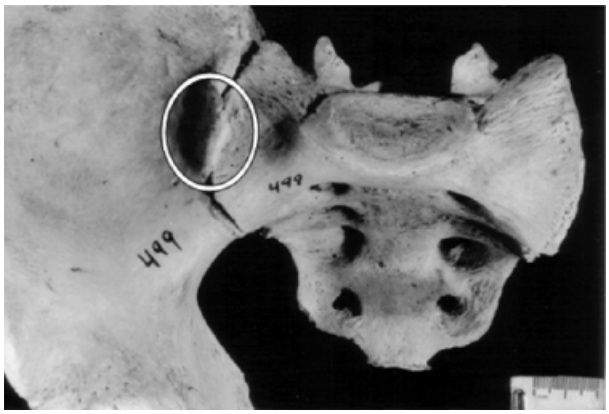

FIG. 2—*Partial sacroiliac joint bridging.*

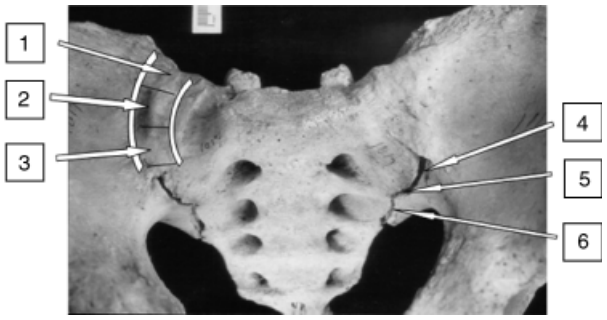

FIG. 3—*Areas of sacroiliac joint bridging.*

cavity) and its margins smoothly join the two bones, away from the "lips" of the articular surface. In the pelvises where only partial bridging was present, it was always iliac in distribution, never as an isolated phenomenon on the sacrum (Fig. 2). Intra-articular bridging lacks the overhanging dome-shaped appearance and manifests as a continuous flat nondemarcated area (Fig. 4).

Type

In males, 97% of the affected individuals manifested extra-articular bridging and only 3% had intra-articular SIB. All nine females with SIB were of the intra-articular type, seven showed bridging of the auricular surfaces (anterior aspect of the joint) and there were two cases of the tuberosities (posterior aspect) (Fig. 7).

Location

Among males, most (72.5%) SIB occurred in the upper part of the sacroiliac joint (areas 1–3). In at least half of the individuals, area 1 was involved. In females, excluding the two cases of total intra-articular ankylosis, the upper part showed evidence of bridging in only two females, but not involving area one. Two of the nine females (22%) and three of the 289 males (1%) with SIB manifested posterior bridging (Fig. 7).

Ethnic Factor

The prevalence of SIB was similar in both African American and white Caucasian males (10.5% vs. 13.2%, respectively) ($\chi^2 = 3.728$, df = 1, $p = 0.0535$).

Age Factor

SIB was age dependent (present in 18% of all males between 50% and 70% and in 30% of all males over 80 years of age).

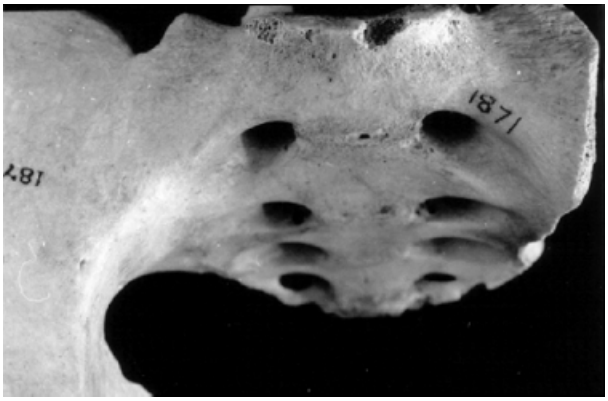

FIG. 4—*Intra-articular bridging of the sacroiliac joint.*

FIG. 5—*Radiograph of sacroiliac joint bridging: note that the interarticular space is normal in size.*

When the sex effect was corrected for age, the following numbers were obtained: SIB was present in 0.05% of females and 8.3% of males under 60 years of age and in 6% of females and 23.6% of males over 60.

Reliability and Validity of the Proposed Criterion

As the criteria for SIB are simple to use and the evaluation does not demand any special technical device, it is not surprising that reliability (inter- and intraobserver error) was found to be very high (reliability coefficient = 0.99).

The issue of validity is more critical as three issues are raised: (a) Do other skeletal populations, similar in age and sex and of similar social and economical background but from different geographical location, manifest similar results? (b) Do other skeletal populations of different geographical origins, environmental conditions, ethnicity, and socio-economic background manifest the same phenomenon? (c) Do archeological populations fit into the picture presented by modern populations?

Stewart's (10) study on sacroiliac ankylosis clarifies the first two issues. He studied two large well-documented skeletal collections: the Terry Collection, which included 1442 African-Americans and Caucasian skeletons (Smithsonian National Museum of Natural History, Washington, DC), and the Dart Collection, which included 544 African Bantu (University of the Witwatersrand Medical School, Johannesburg, South Africa). The frequency of SIB was very similar to our study, with an overwhelming dominance of males over females: 11.2% in males vs. 4.4% in females in American Caucasians, 24.9% vs. 3.0% in African Americans and 8.6% vs. 3.0% in African Bantu.

FIG. 6—*Computed tomography image of left sacroiliac joint bridging.*

TABLE 1—*Distribution of skeletons with SIB, by age and sex.*

Age Group (years)	Males			Females			Total
	N	SIB (*N*)	SIB*	*N*	SIB (*N*)	SIB*	
10–19	22	0	0	19	0	0	41
20–29	207	3	1.45	86	0	0	293
30–39	395	17	4.3	106	2	1.8	501
40–49	584	38	6.5	91	0	0	675
50–59	533	86	16.13	71	0	0	604
60–69	382	78	20.41	50	3	6	432
70–79	176	50	28.4	47	2	4.2	223
80+	56	17	30.35	20	2	10	76
Total	2355	289		490	9		2845

*In % in age group.
SIB, sacroiliac joint bridging.

Stewart's study lends support to three other important observations of our study: (a) extra-articular ankylosis is the result of a process of osteophytosis beginning almost always as a thin lip arising from the ilium, (b) when SIB is present in females, the area adjacent to the arcuate line is involved (areas three and four in our study), and (c) posterior bridging is more common in females (Fig. 7). Taking into consideration SIB frequency and morphology, Stewart described the sex bias of SIB as the almost exclusive occurrence of extra-articular osteophytosis in males.

The second validation comes from Brooke's (11) study carried out on a sample of 210 cadavers. Out of the 105 males, 37% had ankylosed sacroiliac joint, yet all females were free from ankylosing.

Studies on SIB in large skeletal archeological populations are meager due to the limited ability to properly sex the skeletons. The study by Waldron and Rogers (12) using the Spitalfields collection, where definite sexing for some of the skeletons was possible (from names on coffin plates), found that the vast majority (73.2%) of individuals with SIB were males.

Our finding on living population based on CT images gives another validation for the results. Out of 38 males, 34.2% had SIB contrasted with 4.6% of the females (Fig. 6). In fact the rate among females is even smaller (2.3%), as one of our females with SIB also manifested an old fracture of the left innominate bone (which could induce the development of SIB). The high rate of SIB among males in our study is not surprising as most of them were over 60 years (average age 69.6 years). The fact that the CT study, which was based on present-day modern populations and of

TABLE 2—*Association of age, sex, and ethnic origin with SIB: χ^2 test.*

Factor	Sex	Years < 60	Years > 60	*p*-Value
Age	Males	144/1741	145/614	< 0.0001
	Females	2/373	7/117	0.0001
Factor	Data source	Males	Females	*p*-value
Sex	Skeletal	289/2355	9/490	< 0.0001
	CT	13/38	2/43	0.0006
Factor	Sex	Afro-American	Whites	*p*-value
Ethnic	Males	88/837	201/1518	0.0535
	Females*	3/272	6/216	0.1720

*Two females of Asian origin were omitted.

FIG. 7—*Posterior sacroiliac joint bridging.*

different socio-economical background, yielded similar results to that of the skeletal study further supports our claim that the SIB phenomenon is sex dependent and geographical origin, ethnicity, environmental condition, and occupational status independent.

The reasons for the overwhelming prevalence of SIB among males compared with females as well as for the different appearance of the bridging in males and females are not yet clear. A hormonal agent is the major suspect, i.e., the necessity to preserve a functional sacroiliac joint for easier delivery avoids ankylosing of the joints in females. The strong effects of hormones on bone remodeling in females, as in the case of Hyperostosis Frontalis Interna, is well known (13). Alternatively, a mechanical factor can be involved, i.e., the male and female sacroiliac joint are distinct in function, the sacroiliac joint of males is being built for strength and that of the females for parturition (10,11). The sacroiliac joint of males is exposed to greater physical stress and heavier body trunk and upper limbs.

Discussion

This study presents a simple, highly reliable criterion (when present) for sexing the skeleton. Bony evidence on the ilium for a preliminary partial or full extra-articular bridging of the sacroiliac joint, especially when located at the upper part of the joint, indicates a male skeleton.

The fact that the phenomenon of SIB is independent of ethnic origin supports its application for use in all human populations regardless of geographical location and ethnic affinity. This criterion is more applicable in older individuals. While the bony pelvis, due to its complicated anatomical structure, is usually exposed to much more postmortem damage (eliminating the applicability of other criteria mentioned), the para-articular area and auricular surface on the ilium in archeological material is usually preserved. Finally, no prior knowledge, training, or equipment is required when applying this criterion.

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