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Technical Note: Shape Variability Induced by Reassembly of Human Pelvic Bones

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KEY WORDS measurement precision; morphometrics; hip bone; nutation

ABSTRACT In traditional as well as in geometric morphometric studies, the shape of the pelvis is often quantified after the reassembly of the two hip bones and the sacrum. However, on dry bones, the morphology of the cartilaginous tissues that form the two sacroiliac joints and the pubic symphysis before death remains unknown, leading to potential inaccuracies and errors during the reassembly process. A protocol was established to investigate the effects of reassembly on the quantification of pelvis shape. The shape of fresh pelves obtained after dissection, in which the three bones are in an anatomically relevant position, was compared with the shape of different reassemblies based on the individual dry bones of the same individuals. Our results demonstrated a significant effect of the reassembly. Variation in the reassembly process is likely related, first, to the complete absence of cartilaginous tissues on dry bones and, second, to the morphology of the sacroiliac joint which, *in vivo*, allows physiological movements, resulting in different potential positions of the two sacroiliac surfaces relative to one another. However, the artificial variation introduced by the reassembly process appears small compared with the biological variation between the different individuals. Am J Phys Anthropol 000:000–000, 2012. ©2012 Wiley Periodicals, Inc.

At the end of growth, the adult pelvis is composed of three bones, two hip bones, and one sacrum, which are connected through three articulations: two sacroiliac joints and the pubic symphysis. During taphonomical processes, soft tissues present at the level of the articulations are destroyed and the three pelvic bones become separated. In morphometric studies, the shape of the pelvis is often quantified after reassembly of these three bones. However, during reassembly of the morphology of the cartilaginous tissues, which forms the two sacroiliac joints and the pubic symphysis before death remains unknown and its reconstruction may result in potential inaccuracies and errors. Morphometric studies are based on quantitative analyses of morphological variation (e.g., Bookstein, 1991; Dryden and Mardia, 1998; Slice, 2005). In traditional as well as in geometric morphometric studies, it has long been recognized that the methods used to collect data produce artifacts, which introduces additional sources of variation (Davenport et al., 1935; Jamison and Zegura, 1974; von Cramon-Taubadel et al., 2007). In the literature, several methods have been proposed to assess the observer-induced measurement error (see von Cramon-Taubadel et al., 2007, for a recent review) and different studies quantified variation induced by landmark placement (Kohn et al., 1995; Richtsmeier et al., 1995). In the case of shape analysis of the pelvis, although a few authors have attempted to incorporate soft tissue corrections when quantifying the shape of reassembled pelves, either before (Brown et al., 2011) or after taking measurements (Ruff, 1991; Ruff et al., 1997), the magnitude and patterns of shape variability induced by pelvic bone reassembly remain untested. A protocol was established to analyze the effects of reassembly on the quantitative analysis of pelvis shape. The shape of fresh pelves obtained after dissection, in which the three bones are in an anatomically relevant position, was compared with the shape of different reassemblies based on the individual dry bones of the same individuals. The quantification of the shape variation induced by reassembly has applications for anthropologists who quantify morphological variation between different populations and/or different species, and forensic scientists who need to determine the sex, age, stature, and ethnic origin of human skeletal remains (Patriquin et al., 2002; Dedouit et al., 2007).

MATERIAL AND METHODS

After approval by the scientific comity of the "Centre du Don des Corps" (University of Paris Descartes,

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TABLE 1. Two kinds of datasets were acquired: dataset A corresponds to acquisitions on the entire pelves, i.e., the fresh pelves conserving their cartilaginous articulations and the dry pelves after reassembly; dataset B corresponds to acquisitions of homologous landmark and outline coordinates on the three isolated pelvic bones

	Acquisitions for one pelvis	
Dataset A: Entire pelvis	Two acquisitions on the fresh pelvis Three reassemblies by observer n°1 Three reassemblies by observer n°2	Eight entire pelves
Dataset B: Isolated bones	Homologous landmark and outline coordinate acquisition by observer n°1	

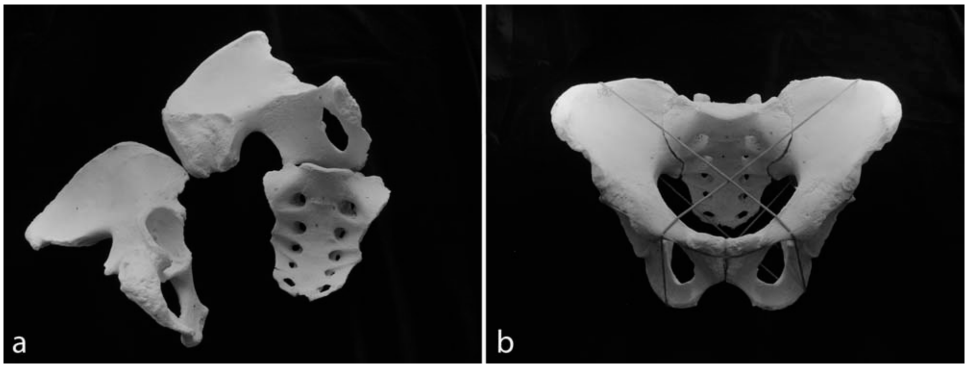

Fig. 1. (**a**) The three bones of the pelvis after osteological treatment. (**b**) Each pelvis was reassembled using rubber bands placed in strategic positions that exploit the biomechanical properties of the pelvis, resulting in a stable reassembly.

France), dissections were performed on 20 nonembalmed cadavers (11 men and 9 women) with a mean age of 76.3 years (SD = 12.4; range = 56–96 years).

The pelvis was removed from all corpses and soft tissues were cut away. Stainless steel nails with a diameter of 1 mm were implanted in each bone of the pelvis to generate a three-dimensional system of reference landmarks. Four nails were implanted in each of the hip bones and four nails in the sacrum, totaling 12 nails per pelvis (see arrows in Fig. 2). These 12 nails were implanted, on the one hand, with a maximal dispersion relative to the overall pelvic volume to produce an accurate three-dimensional system and, on the other hand, in the thickest parts of the bones, e.g., the iliac tubercle and the pelvic brim, to avoid their disassembly during the study period.

Data acquisition

Digitalizations were performed using a MicroScribe® G2 (Immersion) with a precision of ±0.38 mm according to the manufacturer. Three-dimensional coordinates (x, y, z) were recorded in a millimetric orthonormal reference system.

Two kinds of datasets were acquired (Table 1). Dataset A corresponds to acquisitions on entire pelves, i.e., fresh pelves conserving cartilaginous articulations, and dry pelves after reassembly. Dataset B corresponds to an acquisition of homologous landmark and outline coordinates of the three dry bones of each pelvis separately.

Dataset A. Each fresh pelvis was immobilized in a clamp and the coordinates of the 12 nails were digitized at the center of the nail head. This digitization protocol was applied once by two observers.

After dissection, pelves were cleaned and treated at the Service de Préparations Ostéologiques et Taxidermiques (SPOT) of the National Museum of Natural History (Paris, France). The osteological preparation consisted of different baths of alcohols, enzymatic digestion and drying. During osteological treatments, cartilaginous tissues at the level of the sacroiliac joints and pubic symphysis were removed and the three bones were separated (Fig. 1a). In five individuals, the right and/or the left sacroiliac joints were fused or presented osteoarthritis. These subjects were eliminated and thus only 15 individuals, with a mean age of 75.3 years (SD = 14.3; range = 56–96 years) were used in this study. This sample included eight men, with a mean age of 75.8 years (SD = 16.0; range = 57–96 years) and seven women, with a mean age of 74.9 years (SD = 13.3; range = 56–93 years). To test for potential bone deformation induced by osteological preparation, the six Euclidian distances between the four nails of each isolated bone were computed and compared before and after preparation. Given a precision of the Microscribe G2 at 0.38 mm and a nail diameter of 1 mm, we fixed the threshold for error due to protocol-induced measurement error at twice the instrument precision, i.e., 0.76 mm. Differences between distances obtained on isolated bones before and after preparation never reached 0.76 mm, implying no bone deformation during osteological preparations.

For the reassembly of the pelvis, a nonpermanent method was selected that used rubber bands and did not damage the osteological material in contrast to screws and glue. With rubber bands placed in appropriate positions (Fig. 1b), the biomechanical proprieties of the pelvis could be exploited and the reassembly remained stable. Moreover, it was possible to make precise adjustments to obtain accurate reassembly. This method utilizes three to four rubber bands and can be used in any collection. Next, the pelvis was fixed on a table using modeling clay and the coordinates of the 12 nails were digitized. The reassembly was performed three times, one different days, by two observers on each pelvis.

Dataset B. Homologous landmark and outline coordinates were acquired on each dry bone separately. For each hip bone, the coordinates of the four nails, 14

TABLE 2. List of homologous landmarks used in the study

No.	Definition
Coxal	
1	Superior point of the pubic symphysis
2	Junction between the iliopubic (superior public) ramus and the acetabular rim
3	Point in the acetabular rim crossing the continuation of the inferior iliac spine, at the level of the insertion of the iliofemoral ligament
4	Anterior superior iliac spine
5	Extreme of curvature of the iliac (cristal) tubercle at the level of the lateral border of the iliac crest
6	*Spinea limitans*: tubercle forms by the posteroinferior border of the insertion of the muscle *quadratum lumborum*, at the level of the lateral border of the iliac crest
7	Posteroinferior point of the inferior ramus of the sacroiliac joint
8	Extreme of curvature of the greater sciatic notch
9	Ischial spine
10	Most posterosuperior point of the ischial tuberosity, i.e., superior border of the insertion of the muscle *semi-membranosus*
11	At the level of the transversal crest of the ischial tuberosity, junction between the insertion of the muscle *semi-tendinosus* and the muscle *adductor magnus*
12	Inferior point of the pubic symphysis
13	*Scalenion*: tangent point of the line between the acetabular center and the ventral border of the sacroiliac joint (Rickenmann, 1957)
14	Posterior point of the junction between the sacrum and the superior ramus of the sacroiliac joint
Sacrum	
1s	Middle of the right lateral border of the upper plate of the first sacral vertebra
2s	Middle of the left lateral border of the upper plate of the first sacral vertebra
3s	Middle of the junction between the second and third sacral vertebra

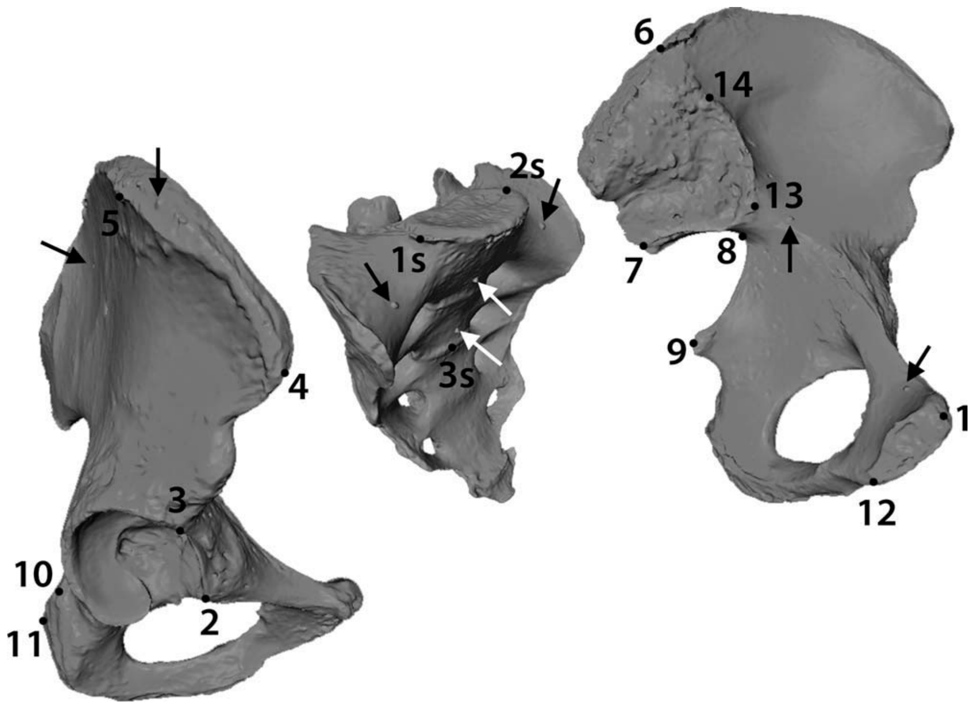

Fig. 2. Homologous landmarks used in the study and further described in Table 2. The scans of the three bones were performed using a Breuckmann® surface scanner. Arrows correspond to the localization of the visible nails. Left: lateral view of the right hip bone; middle: 3/4 view of the sacrum; right: medial view of the left hip bone.

homologous landmarks (Table 2 and Fig. 2) and outline of the *facies lunata* were digitized. For each sacrum the coordinates of the four nails, three homologous landmarks (Table 2 and Fig. 2) and outline of the superior articular plane of the first sacral vertebra were digitized. Outlines were acquired using the MicroScribe, programmed to take coordinates one millimeter apart. They were used afterwards to compute the center and the orientation of the plane of the first sacral vertebra.

The homologous landmarks (Table 2 and Fig. 2) correspond to landmarks classically used in the literature (Weidenreich, 1913; Rickenmann, 1957; Zuckerman et al., 1973; McHenry, 1978; Steudel, 1981; Berge et al., 1984; Berge, 1996, 1998; Bouhallier et al., 2004; Boulay et al., 2006a; Tardieu et al., 2006).

Data processing

The first step of data processing consisted of a reorientation of the homologous landmarks and outlines acquired on the isolated dry bones (dataset B) in the three-dimensional space defined by each of the eight entire pelves per individual, i.e., two fresh pelves and six reassembled pelves (dataset A). The superimposition process based on a generalized procrustes analysis (GPA; Gower, 1975; Rohlf and Slice, 1990) corresponds to a scaling step followed by translations and rigid three-dimensional rotations of the bones, using the landmarks defined by the 12 nails. Homologous landmarks and outlines were only passively superimposed, i.e., the parameters of scaling, translation, and rotation computed during the superimposition process based on nails were applied to the homologous landmarks and outlines. The centroid size of the combined nails coordinates used during the scaling step was restored before further mathematical and statistical treatments because it has no biological meaning. A custom-designed function of the Rmorph library (Baylac, 2010) was used for this superimposition process. All analyses were performed using the R graphical and statistical package v.2.9.0 (R Development Core Team, 2009).

To test for potential movements of bone during coordinate acquisition, the distance between the nails based on the digitization of individual bones versus that of the entire pelvis was calculated. None of the 15 pelves exhibited a mean distance greater than 0.76 mm and all pelves were therefore included in the analyses.

The use of nails as a reference system provided an accurate method to distinguish variation caused by reassembly and observer-induced measurement error. In contrast to biological landmarks the position of the nails is unambiguous. Thus, observer-induced measurement error was eliminated from the data and the effect of the reassembly can be analyzed. However, it should be noted that this approach still confounds variation introduced by reassembly with variation due to measurement instrument error.

The three-dimensional coordinates of the homologous landmarks obtained after the superimposition based on the nail coordinates were used for geometric morphometric analyses. Following a GPA (Gower, 1975; Rohlf and Slice, 1990) based on the homologous landmarks coordinates, tangent space projections were used to compute a principal component analysis (PCA). A multivariate analysis of variance (MANOVA) was performed on the non-null principal components to test the effect of four identified factors: observer (two observers), type of pelvic preparation (fresh and reassembled), repetition (1–3), and sex. The F statistics were estimated from the Pillai's trace as recommended by Hand and Taylor (1987). A canonical variate analysis (CVA) was also performed and visualizations of shape variation along the first and second axis were done using multivariate regressions (Monteiro, 1999).

Based on the three-dimensional coordinates of homologous landmarks and outlines, four linear measurements and two angles were calculated on each pelvis (Fig. 3). Linear breadth measurements included the bi-iliac breadth (Fig. 3a), computed based on the distance between right and left landmark n°5, and the sacroiliac breadth (Fig. 3b), computed based on the distance between the right and left landmark n°13. The distance between the center of the superior articular plane of the first sacral vertebra and the middle of the right and left landmark n°1 of the hip bones was calculated to approximate the traditional measurement of the anteroposterior diameter of inlet (Fig. 3c). The anteroposterior diameter of inlet has traditionally been measured using the anterior border of the sacral promontory rather than its center. The distance between the landmark n°3 of the sacrum and the middle of the right and left landmark n°12 of the hip bones was calculated to approximate the traditional measurement of the anteroposterior diameter of

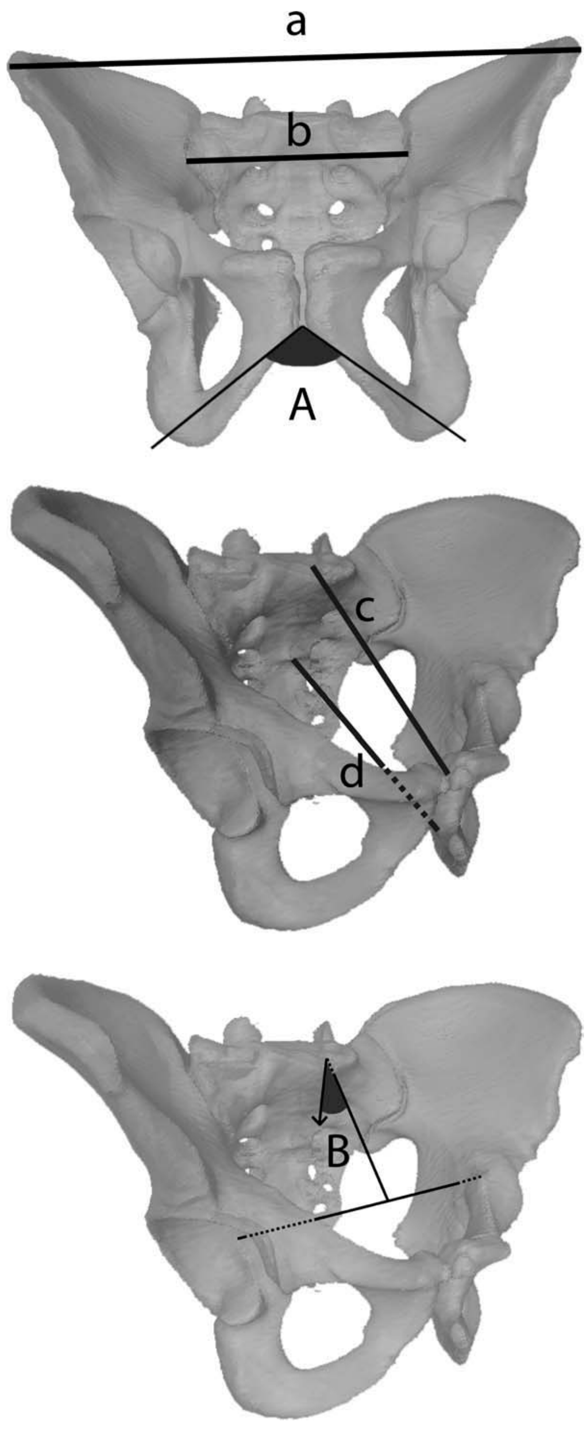

Fig. 3. Four linear measurements and two angles were calculated using the entire pelvis: (**a**) Bi-iliac breadth; (**b**) sacroiliac breadth; (**c**) approximation of the traditional measurement of the anteroposterior diameter of the inlet; (**d**) approximation of the traditional measurement of the anteroposterior diameter of the outlet. (**A**) The angle describing the orientation of the ischiopubic rami. (**B**) The "angle of sacral incidence" describing the three-dimensional orientation of the lumbo-sacral joint.

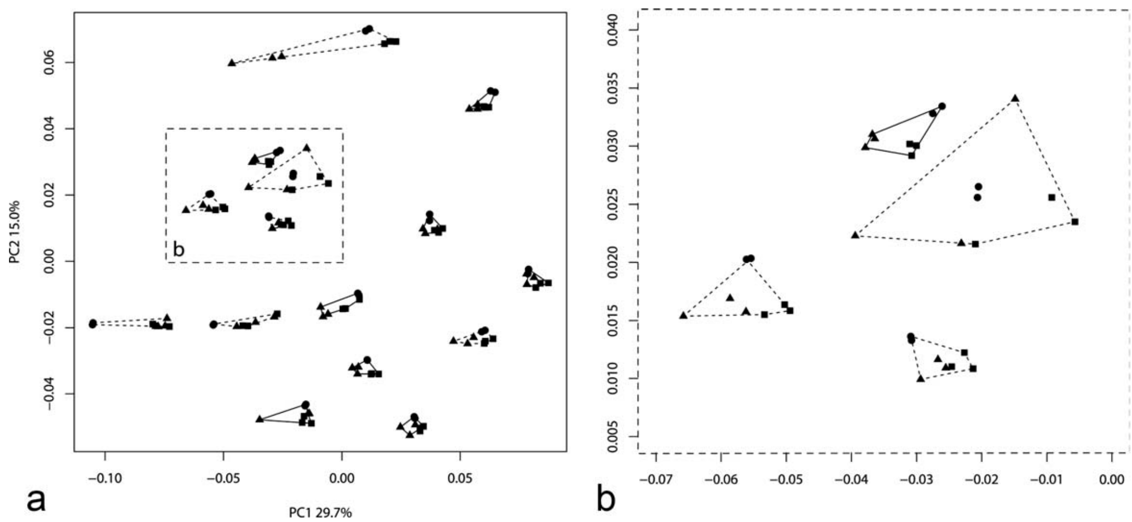

Fig. 4. (**a**) Dispersion along PC1 (29.7% of the variance) and PC2 (15.0% of the variance) of the PCA computed based on the three-dimensional coordinates of the homologous landmarks. Convex polygons enclose each of the 15 individuals: the solid line corresponds to males and the dotted line to females. (**b**) Detail of the four individuals contained by the box in Figure 3a. For each individual, fresh pelvis (circles) and reassemblies performed by the first and second observer (triangles and squares, respectively) are represented.

TABLE 3. Results of the MANOVA

	df	Pillai's trace	*F*	df1	df2	*P*	
Observer (obs)	1	1	3	86	19	0.0021	**
Pelvic preparation (pp)	1	1	17	86	19	<0.001	***
Repetition (rep)	2	2	1	172	40	0.155	NS
Sex	1	1	889,258	86	19	<0.001	***
Obs × rep	1	1	1	86	19	0.203	NS
Obs × sex	1	1	2	86	19	0.108	NS
Pp × sex	1	1	16	86	19	<0.001	***
Obs × rep	2	2	1	172	40	0.165	NS
Sex × rep	2	2	1	172	40	0.664	NS
Obs × pp × sex	1	1	1	86	19	0.864	NS
Obs × sex × rep	2	2	1	172	40	0.639	NS
Residual d.f.	104						

NS, not significant; **, significant at 0.01; ***, significant at 0.001.

outlet (Fig. 3d). The anteroposterior diameter of outlet has traditionally been measured using the apex of the sacrum rather than the junction between the second and third sacral vertebra. The first angle concerned the orientation of the ischiopubic (inferior pubic) rami. To do so, two vectors were computer based on the homologous landmarks n°11 and 12 of each hip bone to obtain the three-dimensional orientation of the right and left ischiopubic rami. The angle between these two vectors forms the angle of the ischiopubic rami (Fig. 3A). Second, to describe the three-dimensional orientation of the lumbosacral joint, the "angle of sacral incidence" was computed (Fig. 3B). This parameter is defined as the angle between the line perpendicular to the superior articular plane of the first sacral vertebra at its center and the line connecting this point to the middle of the interacetabular distance (distance between the centers of the two acetabula) (Duval-Beaupère et al., 1992; Legaye et al., 1993, 1998; Duval-Beaupère and Legaye, 2004; Tardieu, 2006; Boulay et al., 2006b). This angle was computed based on the outline of the superior articular plane of the first sacral vertebra and the outlines acquired along the edge of the right and left *facies lunata*. The outlines acquired along the edge of the *facies lunata* were used to compute a regression based on the equation of a sphere providing the three-dimensional centers of the two acetabula.

For each of these parameters, the differences between the real value, computed using fresh pelvis, and each value obtained using the six reassemblies were calculated. The mean of the absolute difference and the maximal difference were recorded.

Finally, the mediolateral thickness of the pubic symphysis was calculated based on the distance between the right and left superior points of the pubic symphysis (right and left landmark n°1) and the distance between the right and left inferior points of the pubic symphysis (right and left landmark n°12). The mean value of the mediolateral thickness of the sacroiliac joint can be approximated based on the sacroiliac breadth measurements, the variation in the measurement of the sacroiliac breadth between reassembled pelvis and fresh pelvis being considered to be entirely due to the absence of the cartilaginous tissues at the level of the sacroiliac joints. ANOVAs were performed to test the sex effect on the pubic symphysis and sacroiliac joint thicknesses.

RESULTS AND DISCUSSION

Results obtained based on the PCA are represented in Figure 4 illustrating the distribution of the different pelves along PC1 (29.7% of variance) and PC2 (15.0% of variance). The eight points per polygon, corresponding to the two fresh pelves and the six reassembled pelves per individual, are not identical, illustrating the artificial variation introduced by the reassembly process. However, the polygons representing the different individuals never overlap. Consequently, the variation introduced by the reassembly remains smaller than the biological distance between the different individuals. According to the MANOVA, the factors corresponding to observer, the type of pelvic preparation and sex showed a strong and significant effect (Table 3). However, there is no significant difference between the different reassemblies by the

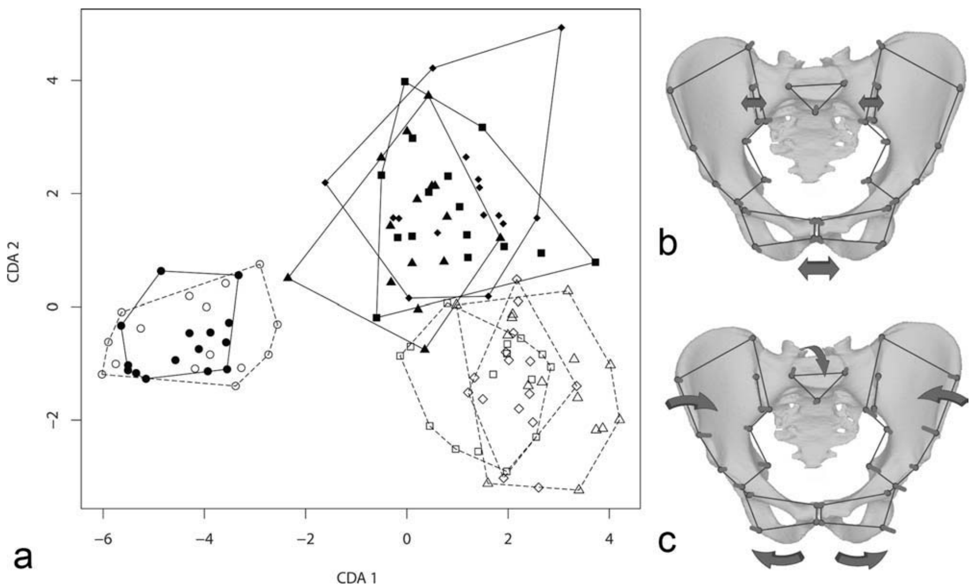

Fig. 5. (**a**) Distribution along the first and second canonical discriminant axes (CDA) of the CVA. The first axis discriminates data acquired on fresh pelves (circles) and data acquired after reassembly using the three dry bones (squares, triangles, and diamonds, respectively, for the first, second, and third reassemblies performed by each observer). The second axis discriminates data acquired by the first observer (open symbols/dotted line) and the second observer (filled symbols/solid line). (**b**) Mean shapes are represented with vectors illustrating deformations (amplified three times) along the first axis. Main variations occurring along the first axis (i.e., shape differences between fresh and reassembled pelvises) were illustrated using arrows. (**c**) Mean shapes are represented with vectors illustrating deformations (amplified three times) along the second axis. Main variations occurring along the second axis (i.e., shape differences between reassembled pelvises performed by the two observers) were illustrated using arrows.

same observer. The inclusion of size in the analysis did not modify these results. Only one interaction term was significant (Table 3), indicating an effect of the pelvic condition according to sex. There is no significant effect of sex in the mediolateral thickness of both the sacroiliac joint estimated based on the sacroiliac breadth and on the pubic symphysis ($P > 0.05$). Thus, the interaction detected in the MANOVA between sex and pelvic preparation (Table 3) cannot be explained by a significant difference in the thickness of the cartilaginous parts between males and females. Bone condition may, in contrast, explain part of the variation. A visual inspection of the bones showed that females are more affected by osteological treatment due to a more pronounced osteoporosis in older females than males. Bones of older females tend to be thinner and more porous and, thus, were more damaged than those of male subjects during the chemical treatment of the bone used to remove soft tissues. Eroded joint surfaces induce variability of the reassembly, and, interestingly, females tended to present more variable reassemblies (Fig. 4). Because of the old age of the female individuals included in our sample, the osteological treatments may have induced some bone damage. However, this erosion was limited and appears minimal compared with the damage resulting from ordinary taphonomical processes.

Shape variations introduced by the reassembly process can be identified along the first and second axis of the CVA: data acquired on fresh pelves and on reassembled pelves can be discriminated on the first axis (Fig. 5a,b); the second axis allows a discrimination of the reassemblies performed by the first and the second observer (Fig. 5a,c).

Differences between fresh and reassembled pelves are mainly located in the thicknesses of the pubic symphysis and sacroiliac joints due to the complete absence of the cartilaginous tissues in dry bones (Fig. 5b). Schroeder et al. (1997) tested the effect of the rearticulation on their pelvic measurements but they reassembled pelves while conserving cartilaginous tissues. Thus, as they noted themselves, this can explain the nonsignificant effect obtained. The variation between reassemblies concerns the orientation of the sacrum and the hip bones (Fig. 5c). Interestingly, this is similar in some ways to the motions identified during nutation and counternutation movements (anteroposterior rotation of the sacrum) *in vivo*. The sacroiliac joint is a diarthrosis with congruent articular surfaces reinforced by a short articular capsule and strong ligaments resulting in a very stable configuration (Kapandji, 2007; Klein and Sommerfeld, 2008). However, although previously contested, rotational movements (nutation and counternutation), around a transverse axis are known to exist (Testut and Latarjet, 1948; Kapandji, 2007; Klein and Sommerfeld, 2008). The recorded amplitude of these movements varies according to different authors from $>10^\circ$ to $<3^\circ$ (Egun et al., 1978; Lavignolle et al., 1983; Jacob and Kissling, 1995; Smidt et al., 1997; Sturesson et al., 2000; Bussey et al., 2004). Yet, according to Klein and Sommerfeld (2008) normal values appear to be around 3°, the greater values reported corresponding to either measurement error or pathological cases and pregnant females (MacLennan et al., 1986; Kristiansson et al., 1996). Movements of the hip bones in the frontal plane as described by Kapandji (2007) during nutation and counternutation were also observed. Indeed, when the sacrum is inclined forward during nutation, i.e., the apex moving to a more posterior position and the sacral plate moving to a more anterior position, the iliac bones move away and ischial bones approach one another. Conversely, during counternutation the iliac bones approach one another and the ischial bones move apart. Although

TABLE 4. Results of the comparison between measurements of the four linear distances and the two angles based on fresh and reassembled pelves

Measurement	Mean value on fresh pelves	Mean value on reassembled pelves	Mean of the differences		Maximal difference	
Bi-iliac breadth (mm)	278.8 ± 16.9	276.4 ± 16.7	3.4 ± 1.4	1.2%	5.4 ± 2.5	1.9%
Sacroiliac breadth (mm)	113.1 ± 7.7	110.6 ± 7.8	2.6 ± 1.0	2.3%	3.7 ± 1.0	3.2%
Anteroposterior diameter of inlet (mm)	137.5 ± 9.8	136.8 ± 10.3	1.0 ± 0.5	0.7%	2.1 ± 0.9	1.5%
Anteroposterior diameter of outlet (mm)	114.7 ± 7.3	113.5 ± 7.4	1.3 ± 0.5	1.1%	2.3 ± 0.7	2.0%
Angle of the ischiopubic rami (°)	82.6 ± 6.3	82.3 ± 5.4	3.0 ± 2.6		5.6 ± 5.0	
Angle of sacral incidence (°)	54.7 ± 11.3	54.9 ± 11.0	1.7 ± 0.7		3.5 ± 1.7	

the sacroiliac joints surfaces generally match well, slight differences in reassembly and positioning of the sacrum may result in corresponding deviation of the hip bones (Fig. 5c).

In summary, according to our geometric morphometric results, a significant effect on shape analyses is introduced by removal of soft tissue and reassembly of the pelvic bones using rubber bands (Table 3). Yet, variation introduced by the reassembly remains small compared with the biological variation observed between the 15 pelves examined (Fig. 4). Variation in the reassembly process is likely related, first, to the complete absence of cartilaginous tissues on dry bones and, second, to the morphology of the sacroiliac joint which, *in vivo*, allows physiological movements, resulting in different potential positions of the two sacroiliac surfaces relative to one another. Using the results obtained in this study, measurements based on rearticulated pelvis can be improved, either by improving the reassembly process performed before measurements or by using corrections which could be performed after measurements.

First, the reassembly process can be improved by placing buffers or clay with a width corresponding to the mean mediolateral thickness of the pubic symphysis and sacroiliac joints. Concerning the pubic symphysis, the mean value calculated in the sample of the 15 individuals equaled 6.84 mm (SD = 2.48; range = 2.90–11.20 mm), a result close to the value of 5.9 mm in males and 4.9 mm in females proposed by Vix and Ryu (1971). The difference between the thickest symphysis and the narrowest symphysis is 8.30 mm, i.e., <1 cm. No significant effect of sex was detected ($P > 0.05$) but no definitive conclusion can be drawn due to the small size and relatively old age of the individuals included in this study.

Concerning the mediolateral thickness of the sacroiliac joints, a mean value can be estimated based on the sacroiliac breadth measurements. The mean difference between reassemblies and fresh pelvis of 2.5 mm suggests an approximate thickness of 1.3 mm for each sacroiliac joint. This value is low compared with the mean thickness of 3.5–4.5 mm obtained on middle-age subjects by MacDonald and Hunt (1952) but is in accordance with the great decrease of the thickness of the cartilage during aging. The advanced age of the subjects used in the study may thus explain the low value of the mean thickness obtained for the sacroiliac joint. Consequently, it would be interesting to analyze younger adults. It should be noted that recommendations proposed to improved reassembly process pertain only to adult pelves. In juvenile pelves, cartilaginous parts remain and the hip bones and the sacrum are composed of many pieces of bone, which remain unfused and are conserved as separated bones in anthropological collections. Consequently, the effect of the reassembly may be very important for young children because not only orientation of the different bones has to be assumed but missing parts exist as well (Watson et al., 2010).

Second, corrections for the reassembly effect on linear and angular measurements of reassembled pelves can be performed using results presented in Table 4. The breadth measurements of the pelvis, represented by the bi-iliac and sacroiliac breadths, appear weakly affected by the reassembly. The bi-iliac breadth is known to be an important parameter to evaluate the body breadth, which can be used in body mass estimation (Ruff et al., 1997), thus suggesting important applications in anthropology (Ruff et al., 1991) as well as in forensic analyses. According to the present results, the bi-iliac breadth becomes smaller when using measurements on reassembled pelves due to the complete absence of the cartilaginous tissues at the joints. To compensate for this absence of cartilage a correction of 2.4 mm is proposed based on our data. However, as was noted previously, the advanced age of the sample almost certainly resulted in cartilaginous thinning and, thus, a greater correction should probably be added for this compensation. The distance approximating the traditional measurements of the anteroposterior diameters of inlet and outlet appear very weakly affected by the reassembly. These parameters, used in obstetrical analyses for example, are weakly affect by the lack of soft tissues, which have their maximal thickness in the mediolateral plane. Measurements in the mediolateral plane, such as the bi-iliac and sacro-iliac breadths, are, thus, more affected by the absence of soft tissues compared with measurements perpendicular to this plane. Concerning the angle of the ischiopubic rami the error introduced by the mean reassembly is low even through it can reach up to 5.6° maximally. This angle reflects the morphology of the subpubic angle, which has implications for sex determination. The pelvis is known to be one of the best skeletal parts to assign sex to skeletal material and both angle of the sciatic notch and subpubic angle are often used in this context both in anthropology and forensic science (Genovés, 1959; Phenice, 1969; Singh and Potturi, 1978; Arsuaga and Carretero, 1994; Luo, 1995; Bruzek, 2002; Patriquin et al., 2002; Takahashi, 2006; Dedouit et al., 2009). According to our results, the subpubic angle could be affected by reassembly, potentially affecting the sex determination. However, the angle of the sciatic notch is invariant and in this respect has an advantage.

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