Journal of Hip Preservation Surgery Vol. 4, No. 1, pp. 97–105
doi: 10.1093/jhps/hnw040
Advance Access Publication 25 November 2016
Research article

OXFORD

Parameters for assessment of the inferior acetabulum morphology in 300 adult hips

Munif A. Hatem[1,2,*], Luiz A. M. da Cunha[2], João C. M. Abdo[2] and Hal David Martin[1]

[1]Hip Preservation Center at Baylor Scott &White Health, Dallas, TX 75246, USA
[2]Department of Orthopaedic Surgery, Universidade Federal do Paraná and Hospital Pequeno Príncipe, Curitiba, PR 80.060-900, Brazil
*Correspondence to: M. A. Hatem. E-mail: munifhatem@gmail.com
Submitted 16 May 2016; revised version accepted 15 October 2016

ABSTRACT

The inferior acetabulum (IA) has been studied as a stabilizer of the hip in flexed positions with potential implications in femoroacetabular impingement and hip instability. However, there is a paucity of studies considering the normal morphology and parameters for assessment of the IA. The purpose of this study was to define parameters to assess the IA morphology and their normal range. Specifically, the objectives were to assess: (i) the width of the anterior horn (AH) and posterior horn (PH) of the acetabulum; (ii) the inclination of the articular surface of the AH angle (AHA) and PH angle (PHA) in the axial plane; (iii) the anterior opening angle of the IA and differences between genders. One hundred and fifty adult skeletons were utilized in this study. Measurements were taken directly from acetabula in 300 innominate bones utilizing digital calipers. In sequence, the innominate bones were assembled to sacrum and 150 pelvises were digitally photographed in standardized positions. Angular parameters of the acetabulum were then measured utilizing the Adobe Photoshop software. The mean width of the AH was 14.80 ± 2.35 mm (range 9.44–20.88). The mean width of the PH was 19.72 ± 2.61 mm (range 13.16–25.86). The AHA was on average 43.58 ± 7.10° (range 24.70–64) and the PHA was on average 36.07 ± 7.54° (16.10–53.20). The mean anterior opening angle of the IA was 25.33 ± 5.40° (10.90–43.10). The IA morphology can be evaluated in all anatomical planes through quantitative parameters. The assessment of the osseous morphology of the IA is the first step to elucidate abnormalities of the IA as potential source of hip pain.

INTRODUCTION

The normal morphology of the acetabular roof and walls is well understood and their abnormalities are known to have deleterious consequences to the hip joint, potentially leading to hip pain and cartilage degeneration [1–4]. Conversely, the inferior portion of the acetabulum has a more complex and not well-understood morphology. The inferior acetabulum (IA) contributes to the stability of the femoral head [5–7] and recent publications have given attention to the potential role of the IA in femoroacetabular impingement [8] and hip instability [9].

The anatomy of the acetabular fossa and IA was studied by Govsa *et al.* in 226 adult acetabula [10]. Those authors described a clover-leaf shape in 60% of the acetabular fossae and observed a smooth unusual facet located anteroinferior to the lunate surface in 62 acetabula (27%) [10]. Steppacher and Lerch [11] studied the size of the semilunar surface in patients with normal and abnormal acetabular coverage, reporting that dysplastic acetabula covered a decreased area of the femoral head anteroinferiorly when compared with normal hips, while hips with acetabular protrusion had an increased coverage [11].

There is a paucity of investigations regarding the normal morphology and assessment of the IA. Most published reports are descriptive or do not provide objective quantitative parameters for the evaluation of the IA [10, 12]. Considering the role of the IA in stabilizing the femoral head and the potential damage associated with femoroacetabular impingement [5–9], there is a need for a better understanding of the IA morphology through parameters allowing a quantitative analysis in different anatomical planes. These parameters would serve as foundation for the assessment of the IA in diagnostic imaging studies of patients with hip pain.

The purpose of this study was to define parameters to assess the IA morphology and their normal range in 300 acetabula of adult cadavers. Specifically, the objectives were to assess: (i) the width of the anterior horn (AH) and posterior horn (PH) of the acetabulum, correlating them with the acetabular diameter; (ii) the inclination of the articular surface of the AH angle (AHA) and PH angle (PHA) in the axial plane, correlating them with the acetabular version; (iii) the angle of cephalization of the AH related to the PH in the sagittal plane, or anterior opening angle of the IA; (iv) differences between genders.

MATERIALS AND METHODS

The Hamann-Todd Osteological Collection at the Cleveland Museum of Natural History contains skeletons collected between 1912 and 1938 in Cleveland, OH, United States. Three hundred adult acetabula (150 pelvic specimens) were obtained from this collection. Eighty acetabula were from African-American females, 80 from Caucasian females, 78 from African-American males and 62 from Caucasian males. The inclusion criteria involved specimens aging from 18 to 50 years (average 34.6 years) at the time of death without signs of arthrosis, fracture or surgical intervention.

The assessment of the IA morphology was first performed through direct measurements in innominate bones individually. In sequence, the right and left innominate bones were rearticulated to sacrum and digital photographs taken in order to assess the angular parameters of the acetabulum in assembled pelvises (Table I). All assessments were performed in each of the 300 acetabula by one examiner.

Table I. Sequence of assessments performed to evaluate the anatomy of the inferior acetabulum

Parameters assessed directly in the acetabula	
	Acetabular diameter
	Width of the AH and PH
Angular parameters measured in photographs	
	AHA and PHA
	Acetabular version
	Anterior opening angle of the inferior acetabulum

AH, anterior horn; PH, posterior horn; AHA, anterior horn angle; PHA, posterior horn angle.

Parameters assessed directly in the acetabula

A digital caliper (500-196-20 Mitutoyo Absolute Digital Caliper, Model CD-6 inches, error 0.01 mm, Mitutoyo Corp., Japan) was utilized for the measurements taken directly from the 300 acetabula.

Acetabular diameter

The acetabular diameter was measured positioning the caliper perpendicular to the plane between the anterior superior iliac spine (ASIS) and pubis (Fig. 1). The diameter was defined as the greatest distance between the anterior and posterior acetabular walls.

Widths of the AH and PH

The width of the AH was measured at 10 mm proximal to its distal limit (Fig. 2). The same method was utilized to measure the width of the PH. Additionally, the relation between the width of each acetabular horn and the acetabular diameter was calculated for all acetabula through the following equation:

$$\frac{\text{AH or PH width}}{\text{Acetabular diameter}}.$$

Angular parameters measured in photographs

Some anatomical and functional aspects of the acetabulum can only be assessed when considering its relation to the

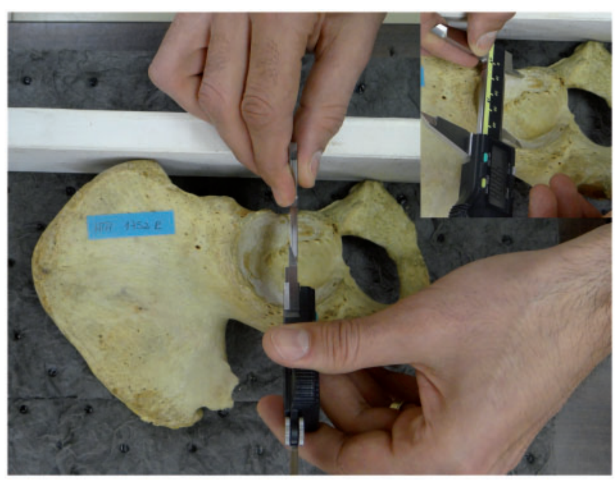

Fig. 1. Assessment of the acetabular diameter, right side. A digital caliper is positioned perpendicularly to the plane between the anterior superior iliac spine and pubis. The measurement is shown in detail in the upper-right hand corner.

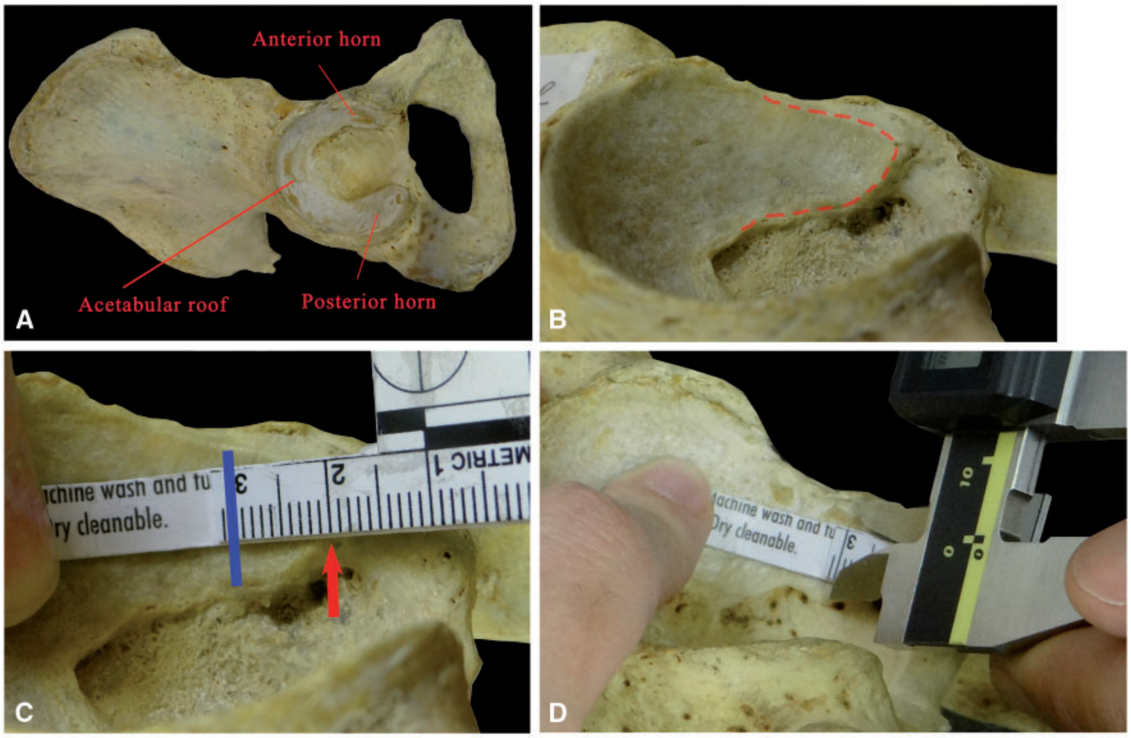

Fig. 2. Anterior and posterior horns of the acetabulum demonstrated in a right innominate bone (**A**) and steps utilized for the measurement of the anterior acetabular horn width; (**B**) direct view of the anterior acetabular horn represented by the dashed red line; (**C**) a flexible ruler was positioned longitudinally to the horn. The arrow indicates the distal limit of the horn and the blue line represents the width of the anterior horn; (**D**) the width of the horn was then measured at 10 mm proximal to the distal limit of the horn.

whole pelvis. Therefore, the angular parameters of the IA were assessed in photographs of rearticulated pelvises. Left and right innominate bones were rearticulated to sacrum utilizing elastic tapes. A piece of foam was used in order to reproduce the pubic symphysis width of 5 mm [13, 14]. In sequence, the pelvis was secured to a customized wood device with additional elastic tapes (Fig. 3). This device was manufactured under control of a digital inclinometer in order to maintain the squareness of the borders. Each pelvis was secured to the device with the ASISs and pubis in the same plane, while the iliac crests were maintained in a neutral stabilized plane [15].

Following the stabilization of each of the 150 rearticulated pelvises, photographs of 300 acetabula were obtained with the acetabula in standard positions and placed at 60 cm from the camera lens and at the center of the image (Fig. 4). This set-up was utilized after preliminary testing in order to avoid inaccurate measurements in consequence of image distortion. A digital inclinometer with resolution of 0.1° was utilized to assure that the camera was positioned within 0.5° from the horizontal. The angular parameters of the IA were then measured in digital photographs utilizing the Adobe Photoshop software version 6.0 (Adobe Systems Corporation, San Jose, CA, United States).

AHA and PHA

The AHA was defined as the angle between the articular surface of the AH and the coronal plane. Likewise, the PHA was defined as the angle between the articular surface of the PH and the coronal plane (Fig. 5). For the assessment of these angles, the rearticulated pelvis was positioned with the distal acetabulum facing the camera at the center of the image. Photographs were taken with a ruler sequentially positioned on the articular surface of the AH and PH, at 10 mm proximal to the distal limit of the respective horn (Fig. 6). Finally, the AHA and PHA were measured on Photoshop.

Acetabular version

Evaluation of the acetabular version was also performed utilizing a ruler with level control positioned at the greatest distance between the anterior and posterior acetabular walls (Fig. 7).

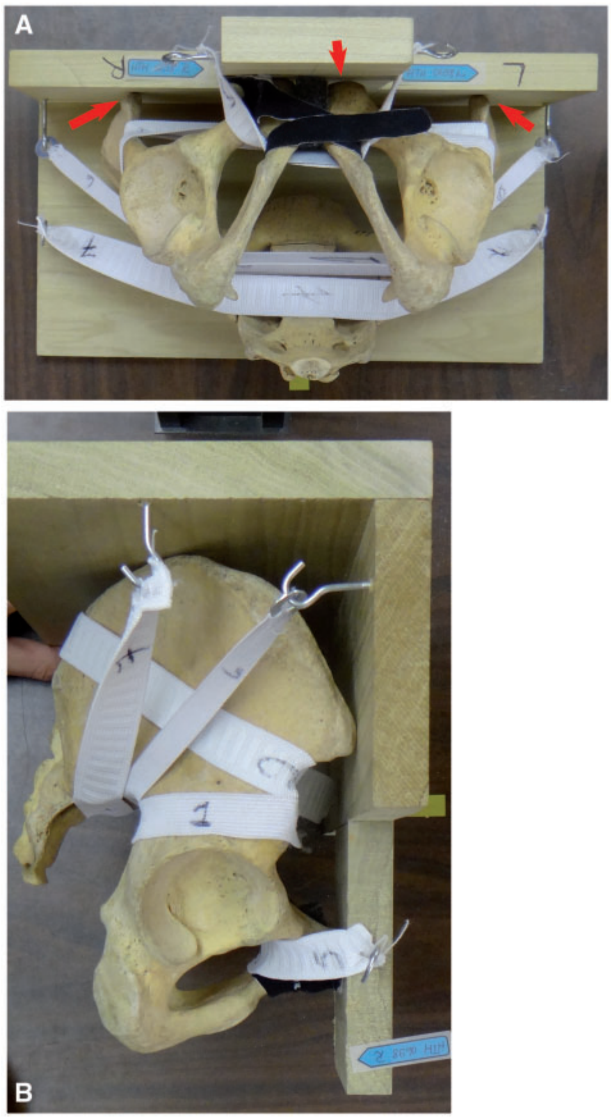

Fig. 3. Rearticulated pelvis. (**A**) Distal view of the rearticulated pelvis secured to a customized wood device utilizing elastic tapes. The anterior superior iliac spines and pubis (arrows) are positioned on the same plane. (**B**) Lateral view.

Anterior opening angle of the IA

The anterior opening angle of the IA represents the degree of cephalization of the AH related to the PH in the sagittal plane. Lateral view photographs of the rearticulated pelvic specimens were used to determine the anterior opening angle of the IA (Fig. 8).

Reliability analysis

In order to evaluate the intra-rater reliability of the assessments involving direct measurement with calipers (acetabular diameter and width of the anterior and PHs), a second measurement was performed in 28 acetabula randomly chosen from the 300 acetabula initially measured. The second measurement was performed by the same observer and compared with the first measurement performed at least 3 days earlier. The intra-rater reliability of the measurements performed with calipers demonstrated sub-millimeter mean differences with intraclass correlation coefficients (ICC) of 0.99, 0.95 and 0.98 for the acetabular diameter, width of the AH and width of the PH, respectively.

The additional assessments of the IA involved measurements performed in photographs of rearticulated pelvises. For those assessments, the reliability analysis also included 28 acetabula randomly chosen from the 300 acetabula initially measured. The reliability of the measurements was evaluated in three ways: (i) intra-rater reliability comparing the original measurement to another measurement of the same photograph performed with time interval greater than 1 month; (ii) reliability comparing the original measurements to measurements performed in different photographs of 28 acetabula of reassembled and repositioned pelvises, more than 3 days after the initial photograph; (iii) inter-rater reliability of measurements performed by 2 observers in the same photograph of 28 specimens. The intra- and inter-rater reliability analyses for the assessments performed in photographs of rearticulated pelvises are presented in Table II.

Statistical analysis

Student's *t* tests for independent samples were utilized to establish the significance of any noted differences and P values of <0.01 were considered significant. The mean of the measurements performed in the right and left acetabula of each pelvis was considered to assess gender-related differences. Pearson's coefficients were calculated to examine correlations between variables.

RESULTS

The mean width of the AH was 14.80 ± 2.35 mm (range 9.44–20.88) (Table III). The mean width of the PH was 19.72 ± 2.61 mm (range 13.16–25.86), being significantly higher than the width of the AH ($P < 0.001$). The relation between the width of the AH and the acetabular diameter was 0.31 ± 0.05 (range 0.17–0.44). The relation between the width of the PH and the acetabular diameter was 0.41 ± 0.04 (range 0.29–0.56). The mean width of the AH was 14.11 ± 1.89 mm (range 9.87–19.80) in female and 15.58 ± 2.16 mm (range 9.44–20.88) in male acetabula (Table IV). The mean width of the PH was 18.15 ± 1.84 mm (range 13.16–24.19) in female and 21.50 ± 1.88 mm (range 15–25.86) in male acetabula. Male presented values significantly greater than female when considering the

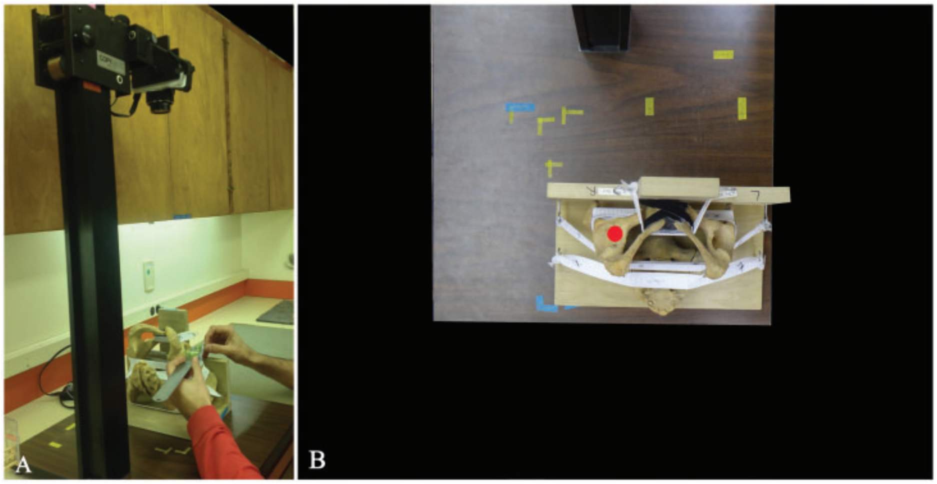

Fig. 4. Set up for the photographs of the pelvises specimens. (**A**) Three hundred acetabula (150 pelvises) were positioned at 60 cm from the camera lens. (**B**) The acetabulum was positioned at the center of the image (red circle).

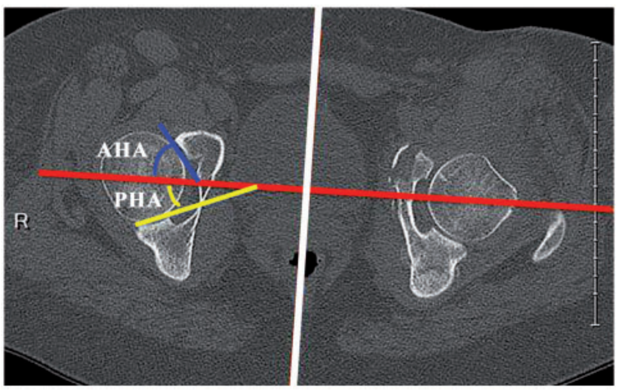

Fig. 5. Axial CT scan of the pelvis illustrating the anterior horn angle (AHA) and posterior horn angle (PHA). The angle between the articular surface of the AH (blue line) and the coronal plane (red line) represents the AHA. The angle between the articular surface of the PH (yellow line) and the coronal plane (red line) represents the PHA.

absolute width of AH ($P < 0.001$) and PH ($P < 0.001$). However, when corrected to the acetabular size, no gender-related difference was observed in the width of the AH ($P = 0.228$) (Table IV).

The AHA was on average 43.58 ± 7.10° (range 24.70–64) and the PHA was on average 36.07 ± 7.54° (16.10–53.20). There was a moderate to strong correlation between the acetabular version and the AHA ($r = 0.64$) and PHA ($r = -0.59$). The mean AHA in female acetabula (44.37 ± 6.93°) was not significantly different from male acetabula (42.69 ± 6.10°) ($P = 0.12$). However, the mean PHA in female acetabula (31.59 ± 5.95°) was significantly lower than in male acetabula (41.19 ± 4.84°) ($P < 0.001$).

The opening angle the IA was on average 25.33 ± 5.40° (range 10.90–43.10). The mean opening angle of the IA in female acetabula (25.82 ± 4.83°) was not significantly different from the male acetabula (24.78 ± 5.19°) ($P = 0.21$).

DISCUSSION

This study found the absolute width of the AH and PH to be significantly increased in male acetabula compared with female acetabula. However, when considering the diameter of the acetabulum relative to the width of the AH, there was no gender-dependent difference. Steppacher and Lerch [11] investigated the acetabular lunate surface based on 164 magnetic resonance (MRI) arthrographies of patients with normal and abnormal acetabula morphology. Those authors reported increased absolute size of the lunate surface in male and no gender-dependent differences in the relative size.

The concept utilized to define the AHA and PHA was based on the well-known acetabular inclination or Tönnis angle, which refers to the inclination of the acetabular roof in the coronal plane [16, 17]. As for the Tönnis angle, increases in the AHA and PHA represent a decline in hip stability. The anteversion of the acetabulum as a whole explained at least part of the variation in the AHA and PHA among the specimens, since that a moderate to strong correlation was found between the acetabular version and the AHA ($r = 0.64$) or PHA ($r = -0.59$). Female acetabula had a significantly lower PHA when compared with male acetabula. Additionally, the acetabular version in female acetabula was higher than male acetabula. Those findings indicate that, in the 150 pelvises included in this

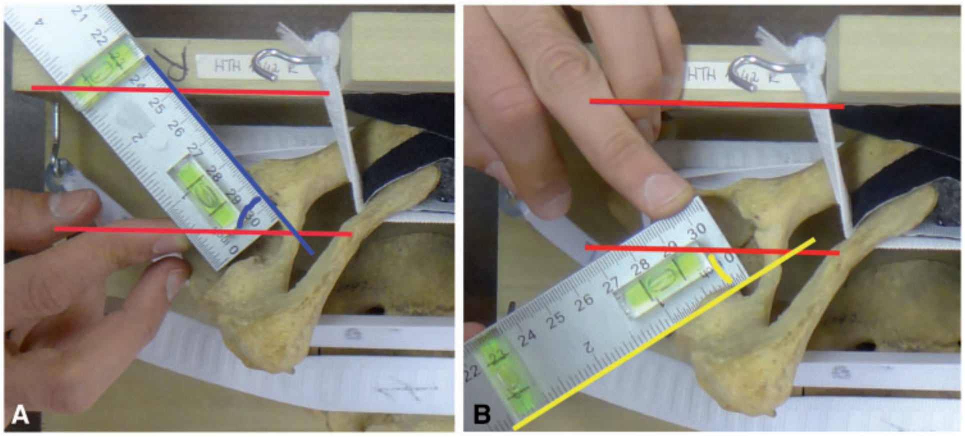

Fig. 6. Distal view of the right acetabulum for assessment of the anterior horn angle (AHA) and posterior horn angle (PHA). (**A**) A ruler is placed on the articular surface of the anterior acetabular horn, at 10 mm proximal to its distal limit. Two level instruments (10 mm of width) were attached to the ruler to control its positioning on the axial plane, and also to guide the placement at 10 mm from the distal limit of the horn. The angle between the ruler (red line) and the coronal plane (blue line) represents the AHA. (**B**) PHA angle.

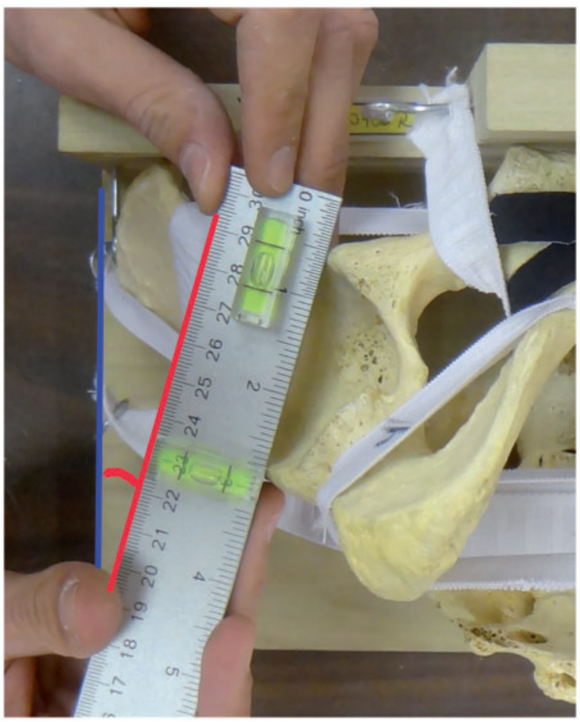

Fig. 7. Assessment of the version in a right acetabulum. A ruler is positioned horizontally at the greatest diameter of the acetabulum. The angle between the ruler (red line) and the sagittal plane (blue line) represents the degree of acetabular anteversion.

study, the female acetabula demonstrated a more stable posterior inferior osseous morphology and less stable anterior osseous morphology when compared with male acetabula. Although the previous authors did not specifically

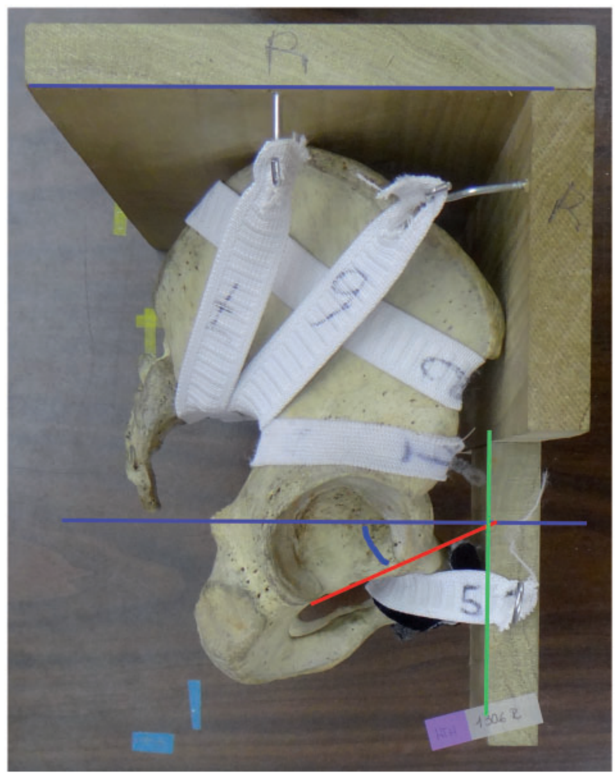

Fig. 8. Measurement of the anterior opening angle of the inferior acetabulum. A line is drawn (red line) between the distal ends of the anterior and posterior acetabular horns. A second line (blue line) is drawn perpendicular to the plane of the anterior superior iliac spines and the pubis (green line). The angle between the red and blue lines corresponds to the anterior opening angle of the inferior acetabulum.

Table II. Reliability of the inferior acetabulum assessments performed in photographs of rearticulated pelvises

Assessment	*ICC, intra-rater*[a]	*ICC, intra-rater*[b]	*ICC, inter-rater*[c]
AHA	0.99	0.95	0.99
PHA	0.99	0.98	0.99
Acetabular version	0.99	0.98	0.99
Anterior opening angle of the IA	0.98	0.95	0.97

AHA, anterior horn angle; PHA, posterior horn angle.

[a]ICC, intra-rater, remeasure performed in the same photograph of 28 specimens.

[b]ICC, intra-rater, remeasure performed in two different photographs of 28 specimens reassembled in different times.

[c]ICC, inter-rater, remeasure performed by two observers in the same photograph of 28 specimens.

Table III. Parameters of the IA for the entire sample (300 acetabula)

Assessment	*Mean (±SD)*	*Range*
Acetabular diameter (mm)	48.36 (±3.89)	39.80–58.25
Width of the AH (mm)	14.80 (±2.35)	9.44–20.88
$\frac{\text{Width of the AH}}{\text{Acetabular diameter}}$	0.31 (±0.05)	0.17–0.44
Width of the PH (mm)	19.72 (±2.61)	13.16–25.86
$\frac{\text{Width of the PH}}{\text{Acetabular diameter}}$	0.41 (±0.04)	0.29–0.56
AHA	43.58° (±7.10)	24.70–64°
PHA	36.07° (±7.54)	16.10–53.20°
Version of the acetabulum	18.93° (±5.74)	5.80–38.30°
Opening angle of the IA	25.33° (±5.40)	10.90–43.10°

IA, inferior acetabulum; AH, anterior horn; PH, posterior horn; AHA, anterior horn angle;
PHA, posterior horn angle.

study the morphology of the IA, their findings also indicate a less stable anterior acetabulum in females in comparison to males [18–20]. McKibbin reported a mean anteversion of 19° in females and 14° in males when comparing 30 adult acetabula of each gender [21]. Maruyama *et al.* compared 50 female with 50 male acetabula and found a mean acetabular anteversion of 21.3° and 18.5° in females and males, respectively [19]. Köhnlein *et al.* reported a mean acetabular anteversion of 21.0 ± 6.7 in 16 female acetabula and 16.9 ± 4.8 in 42 male acetabula [18]. Regarding the

Table IV. Parameters of the IA according to the gender in 300 acetabula

Assessment	*Gender*	*Mean (±SD)*	*P value*
Acetabular diameter (mm)	F	45.53 (±2.21)	<0.001
	M	51.60 (±2.58)	
Width of the AH (mm)	F	14.11 (±1.89)	<0.001
	M	15.58 (±2.16)	
$\frac{\text{Width of the AH}}{\text{Acetabular diameter}}$	F	0.31 (±0.04)	0.228
	M	0.30 (±0.04)	
Width of the PH (mm)	F	18.15 (±1.84)	<0.001
	M	21.50 (±1.88)	
$\frac{\text{Width of the PH}}{\text{Acetabular diameter}}$	F	0.40 (±0.04)	0.003
	M	0.42 (±0.04)	
AHA	F	44.37° (±6.93)	0.120
	M	42.69° (±6.10)	
PHA	F	31.59° (±5.95)	<0.001
	M	41.19° (±4.84)	
Version of the acetabulum	F	21.23° (±4.69)	<0.001
	M	16.30° (±4.79)	
Opening angle of the IA	F	25.82° (±4.83)	0.21
	M	24.78° (±5.19)	

IA, inferior acetabulum; AH, anterior horn; PH, posterior horn; AHA, anterior horn angle; PHA, posterior horn angle.

possible applicability of the AHA and PHA in imaging studies of individuals with hip pain, axial MRI or computed tomography (CT) images at 1 cm proximal to the distal end of the respective horn would represent the measurements performed in this study (Fig. 5).

The anterior opening angle of the IA was measured in a standard positioning of the pelvis with the ASISs and pubis in the same plane (Fig. 8) [15, 20]. Therefore, the mean IA opening angle of 25.33° (range 10.90–43.10°) represents a static measurement in a standard positioning. When analyzing living individuals, the positioning of the acetabulum in the sagittal plane may also be changed according to the pelvic tilt of each individual [21, 22, 23, 15]. Additionally, different activities may influence the positioning of the pelvis in the sagittal plane, increasing or decreasing the slope [21, 23]. The positioning of the acetabulum in the sagittal plane, or acetabular tilt, has been reported as

18.3° by Oberländer *et al.* and 18.9° by Köhnlein [18, 24]. The acetabular tilt is measured between the frontal plane and the acetabular meridian line from 12:00 to 6:00 (acetabular notch) [18]. However, in opposition to the opening of the IA described in our study, the distal end of the articular surface of the AH and PH of the acetabulum are not considered in the acetabular tilt measurement. We considered important to include the distal ends of the AH and PH in the evaluation of sagittal plane positioning of the IA, since that the AH and PH can have variable distal extension related to the acetabular notch and this do not directly articulate with the femoral head. Analyzing the variability observed in the IA opening angle of the 300 hips studied (mean 25.33°, SD ± 5.40, range 10.90–43.10°), the opening angle of the IA may influence the antero and posteroinferior osseous stability of the hip even if the AH and PH inclination and width are within the normal range. In a clinical scenario, the assessment of the opening angle of the IA and the width of the AH and PH would demand the application of three-dimensional reconstruction in MRI or CT images.

This study presents certain limitations. First, the 300 studied acetabula were not radiographically screened for developmental dysplasia. Considering that the post-natal development of the roof and acetabular horns is based on the same semilunar cartilaginous component [25, 26], it is probable that dysplastic hips present decreased width of the AH and PH and increased AHA and PHA. However, this factor in unlikely to significantly influence the results considering the number of acetabula studied and the low prevalence of dysplasia in mixed gender and race populations as in this investigation. Second, AHA, PHA, version and opening angles were measured in assembled pelvises including only bony components. The absence of the sacroiliac joint cartilage and pubic symphysis could change the orientation of the acetabulum when compared with living individuals. To minimize its potential influence, the pubic symphysis was reproduced with a piece of foam of 5 mm [13, 14]. The sacroiliac joint cartilage was not reproduced considering that its combined thickness is on average only 2.6 mm [27, 28]. Additionally, reproducing the sacroiliac joint cartilage would hinder the assembly of the sacrum to the innominates, unless performed with glue, potentially damaging the specimens. Third, the absence of a second observer measurement for the acetabular diameter and width of the horns is another limitation of this study. Fourth, the skeletons utilized in this study were collected between the years of 1912 and 1938. Modifications on lifestyle along the years may have influenced the morphology of the pelvis and acetabulum when compared with today's population.

Finally, this study reports objective parameters to evaluate the morphology of the IA and its relation to the pelvis in all anatomical planes. The availability of axial and tridimensional imaging studies of the acetabulum could allow the utilization of the assessments described in this study to evaluate patients with hip pain. However, the applicability of the measurements and their normal range in imaging studies needs to be investigated. Considering the role of the IA in hip stabilization, the assessment of the osseous morphology of the IA is the first step to elucidate abnormalities of the IA as a potential source of hip pain.

ACKNOWLEDGEMENTS

The authors wish to thank Francine P. Hatem (Curitiba, PR, Brazil) for contributing with the organization and data collection of this research. The authors would also like to show their gratitude to Lyman M. Jellema (Cleveland, OH, United States) for his assistance with the methodology and specimen organization.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sector.

CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES

1. Beck M, Kalhor M, Leunig M *et al*. Hip morphology influences the pattern of damage to the acetabular cartilage: femoroacetabular impingement as a cause of early osteoarthritis of the hip. *J Bone Jt Surg Br* 2005; **87**:1012–8.
2. Ganz R, Parvizi J, Beck M *et al*. Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clin Orthop Relat Res* 2003; 112–20.
3. Jacobsen S, Sonne-Holm S. Hip dysplasia: a significant risk factor for the development of hip osteoarthritis. A cross-sectional survey. *Rheumatol* 2005; **44**:211–8.
4. Tönnis D, Heinecke A. Acetabular and femoral anteversion: relationship with osteoarthritis of the hip. *J Bone Jt. Surg Am* 1999; **81**:1747–70.
5. Eckstein F, von Eisenhart-Rothe R, Landgraf J *et al*. Quantitative analysis of incongruity, contact areas and cartilage thickness in the human hip joint. *Acta Anat* 1997; **158**:192–204.
6. Harris MD, Anderson AE, Henak CR *et al*. Finite element prediction of cartilage contact stresses in normal human hips. *J Orthop Res* 2012; **30**:1133–9.
7. Yoshida H, Faust A, Wilckens J *et al*. Three-dimensional dynamic hip contact area and pressure distribution during activities of daily living. *J Biomech* 2006; **39**:1996–2004.
8. Tibor LM, Ganz R, Leunig M. Anteroinferior acetabular rim damage due to femoroacetabular impingement. *Clin Orthop Relat Res* 2013; **471**:3781–7.

9. Martin RL, Palmer I, Martin HD. Ligamentum teres: a functional description and potential clinical relevance. *Knee Surg Sport. Traumatol Arthrosc* 2012; **20**:1209–14.
10. Govsa F, Ozer MA, Ozgur Z. Morphologic features of the acetabulum. *Arch Orthop Trauma Surg* 2005; **125**:453–61.
11. Steppacher S, Lerch T. Size and shape of the lunate surface in different types of pincer impingement: theoretical implications for surgical therapy. *Osteoarthr. Cartil* 2014; **22**:951–8.
12. Gupta V, Choudhry R, Tuli A *et al*. Unusual facets on the acetabulum in dry adult human coxal bones: a morphological and radiological study. *Surg Radiol Anat* 2001; **23**:263–7.
13. Muecke EC, Currarino G. Congenital widening of the pubic symphysis: associated clinical disorders and roentgen anatomy of affected bony pelves. *Am J Roentgenol Radium Ther Nucl Med* 1968; **103**:179–85.
14. Vix VA, Ryu CY. The Adult Symphysis Pubis: Normal and Abnormal. *AJR Am J Roentgenol* 1971; **112**:517–25.
15. Siebenrock KA, Kalbermatten DF, Ganz R. Effect of pelvic tilt on acetabular retroversion: a study of pelves from cadavers. *Clin Orthop Relat Res* 2003; 241–8.
16. Clohisy JC, St John LC, Schutz AL *et al*. A systematic approach to the plain radiographic evaluation of the young adult hip. *J Bone Jt Surg Am* 2008; **90(Suppl. 4)**:47–66.
17. Tönnis D, Legal H, Graf R *et al*. *Congenital Dysplasia and Dislocation of the Hip in Children and Adults*, 1st edn. Berlin, Heidelberg: Springer-Verlag, 1987.
18. Köhnlein W, Ganz R, Impellizzeri FM *et al*. Acetabular morphology: implications for joint-preserving surgery. *Clin Orthop Relat Res* 2009; **467**:682–91.
19. Maruyama M, Feinberg JR, Capello WN *et al*. The Frank Stinchfield Award: morphologic features of the acetabulum and femur: anteversion angle and implant positioning. *Clin Orthop Relat Res* 2001; 52–65.
20. Mckibbin B. Anatomical factors in the stability of the hip joint in the newborn. *J Bone Jt. Surg Br* 1970; **52**:148–59.
21. DiGioia AM, Hafez MA, Jaramaz B *et al*. Functional pelvic orientation measured from lateral standing and sitting radiographs. *Clin Orthop Relat Res* 2006; **453**:272–6.
22. Nishihara S, Sugano N, Nishii T *et al*. Measurements of pelvic flexion angle using three-dimensional computed tomography. *Clin Orthop Relat Res* 2003; 140–51.
23. Philippot R, Wegrzyn J, Farizon F *et al*. Pelvic balance in sagittal and Lewinnek reference planes in the standing, supine and sitting positions. *Orthop Traumatol Surg Res* 2009; **95**:70–6.
24. Oberländer W, Kurrat HJ, Breul R. Examination of the extension of the osseous facies lunata. A functional study. *Z Orthop Ihre Grenzgeb* 1978; **116**:675–82.
25. Ponseti IV. Growth and development of the acetabulum in the normal child. Anatomical, histological, and roentgenographic studies. *J Bone Jt. Surg Am* 1978; **60**:575–85.
26. Strayer LM. Embryology of he human hip joint. *Clin Orthop Relat Res* 1971; **74**:221–40.
27. McLauchlan GJ, Gardner DL. Sacral and iliac articular cartilage thickness and cellularity: relationship to subchondral bone end-plate thickness and cancellous bone density. *Rheumatol* 2002; **41**:375–80.
28. Salsabili N, Valojerdy MR, Hogg DA. Variations in thickness of articular cartilage in the human sacroiliac joint. *Clin Anat* 1995; **8**:388–90.