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Acetabular rim length: an anatomical study to determine reasonable graft sizes for labral reconstruction

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ABSTRACT

The purpose of this article is to determine normative values for the length of the acetabular rim and detect differences between gender, age, ethnicity, height and leg length. Six measurements were taken on the acetabular rim of 143 cadaveric skeleton specimens (286 acetabula) using a coordinate-measuring device: circumferential (excluding acetabular notch), anterior inferior iliac spine (AIIS)-anterior, AIIS-posterior, 12–3 o'clock, 12–9 o'clock and 11–5 o'clock. Museum specimen height data and leg length data from a previous study were recorded for 109 of 143 specimens. Intraclass correlation coefficients were calculated. Student *t*-tests compared mean values. Multiple regression analysis was used to determine the relationship between acetabular rim length and gender, age, ethnicity, height and leg length. The average acetabular rim length in males for circumferential, AIIS-anterior, AIIS-posterior, 12–3, 12–9 and 11–5 o'clock were 15.8, 4.2, 11.7, 4.9, 4.7 and 9.5 cm, respectively; and for females: 13.7, 3.7, 10.0, 4.3, 4.1 and 8.3 cm, respectively. Intraclass correlation coefficients were 0.953, 0.930, 0.958, 0.857, 0.913 and 0.951, respectively, for each measurement. All six measurements were significantly larger for males ($P < 0.001$). Multiple regression analysis demonstrated a significant relationship between gender and rim length for all six measurements ($P < 0.001$) and between height and leg length and acetabular rim length for five of the six measurements exclusive of AIIS-anterior ($P < 0.001$). No significant trends between age or ethnicity and rim length were found. Average acetabular rim lengths were established. The acetabular rim is significantly longer in males and correlates with height and leg length. Age and ethnicity do not appear to be significant predictors of acetabular rim length. Normative values for acetabular rim lengths may assist in hip preservation surgery.

INTRODUCTION

Femoroacetabular impingement (FAI) is increasingly recognized as a cause of hip pain in young, active adults [1, 2]. The pathologic contact between the acetabular rim and the femoral head-neck junction can lead to labral tears and detachment at the chondrolabral junction [3, 4]. Strategies of treating labral tears continue to evolve with our understanding of labrum physiology and function. Recent studies imply that the labrum performs an important role in hip stability and decreasing contact stresses across the hip joint [5–8]. The biomechanical case for labral preservation can be made, and outcomes studies are beginning to suggest the same [9–11]. However, not all tears are reparable, and occasionally the surgeon is faced with a previously debrided labrum. Labral reconstruction may be indicated in these instances. Multiple reconstruction techniques have been described previously [12–14]. This requires working in the central and peripheral compartments around the acetabular rim, and a sound understanding of peri-acetabular arthroscopic anatomy is required to successfully treat these lesions.

No study has looked specifically at overall acetabular rim lengths or rim arc lengths that must be spanned by a graft during total and subtotal labral reconstructions. If known, this would add to our overall understanding of peri-acetabular morphology and may assist with operative planning during arthroscopic hip preservation surgery. In addition, known differences exist between male and female hip morphology including femoral version, acetabular version and acetabular diameter [15–18]. Given these known differences, a significant difference in acetabular rim size between males and females is expected, but has not been documented in the literature. The purpose of this study was to (i) quantify acetabular rim lengths as it relates to the acetabular clock face and (ii) determine if a difference exists between males and females and whether this difference is age, ethnicity, height or leg-length dependent. We hypothesize that females will have smaller acetabular rim lengths that correlate with height and leg-length, age and ethnicity.

MATERIALS AND METHODS

Acetabular rim and leg length measurements

The study utilized the Hamann-Todd Human Osteological Collection at the Cleveland Museum of Natural History; a large cadaver based collection containing more than 3000 cadaver-derived human skeletons collected between 1912 and 1938. One hundred and forty-three intact human pelvises without gross defects or abnormalities were selected for measurements. Specimens had been previously stripped of soft tissue by boiling, and the bone had been cleaned with brushes prior to degreasing with trichloromethane.

As described previously [19, 20], a standard clock face was used for data collection. The midpoint of the acetabular notch served as the 6 o'clock position as the transverse acetabular ligament was not present on the specimens. A line was drawn between the anterior and posterior horns of the lunate facet and the midpoint was measured and referenced as the 6 o'clock position. A point 180° from this served as the 12 o'clock position. The clock face was drawn on each acetabulum by making a best fit circle over the acetabular rim using a circular goniometer. Every 30° corresponded to 1 h on the clock face. The right acetabulum was used as the template for the clock face, and the clock face positions were inverted on the left acetabulum for consistency of interpretation (Fig. 1A). Both right and left sides were measured for a total of 286 acetabula.

A coordinate-measuring device (MicroScribe MX; GoMeasure3D, Amherst, Virginia) with a needle-point tip and a previously reported accuracy of 0.113 mm was used to manually collect data points [21]. All data points were recorded by one author (J.K.). A random subset of 20 acetabula was measured by a second study author (M.R.K.) in order to calculate inter-observer reliability. Measurements taken included (i) the circumferential distance (excluding the acetabular notch), (ii) the middle of anterior inferior iliac spine (AIIS) ridge anteriorly to the anterior aspect of acetabular notch, (iii) the middle of AIIS ridge posteriorly to the posterior aspect of the acetabular notch, (iv) 12–3 o'clock, (v) 12–9 o'clock and (vi) 11–5 o'clock (Fig. 1B). A data point was recorded along the acetabular rim at every 10° along each rim arc. The distance between data points was calculated as the three-dimensional linear distance. The sum of these 10° increments was recorded in accordance with the six aforementioned measurements.

The post-mortem height data retrieved at time of specimen acquisition nearly 100 years ago was available for 124 of the specimens. Because study methodology of height measurement could not be verified, leg lengths were also used as a surrogate for height. Leg-lengths (femur + tibia) for 109 of our specimens were available from a prior study using the same osteological collection [22]. Femoral lengths were measured from the femoral condyles to the femoral head, and tibial lengths were measured from the lateral tibial plateau to the lateral tibial plafond. The femoral and tibial lengths on each side were then added to form a composite leg length. The height of the foot was not accounted for in this study.

Statistics

Statistics were performed using SPSS Statistics Version 20 (IBM, Armonk, NY, USA). Intraclass correlation (ICC's) coefficients were calculated. We considered an ICC of <0.4 to be poor, 0.4–0.75 to be fair to good and >0.75 to be excellent based on established recommendations [23, 24]. Student *t*-tests were used to assess statistical significance for rim length measurements between males and females. We utilized two sets of multiple regression analyses which factored in age, gender, race and femur/tibia length and a second analysis with height in place of leg length. Femur/tibia length and height were used in separate analyses because of the large correlation between these two variables. Separate analyses were run with the dependent variable set for each of the six acetabular rim measurements; (i) circumferential distance, (ii) middle of AIIS ridge anteriorly to the acetabular notch, (iii) middle of

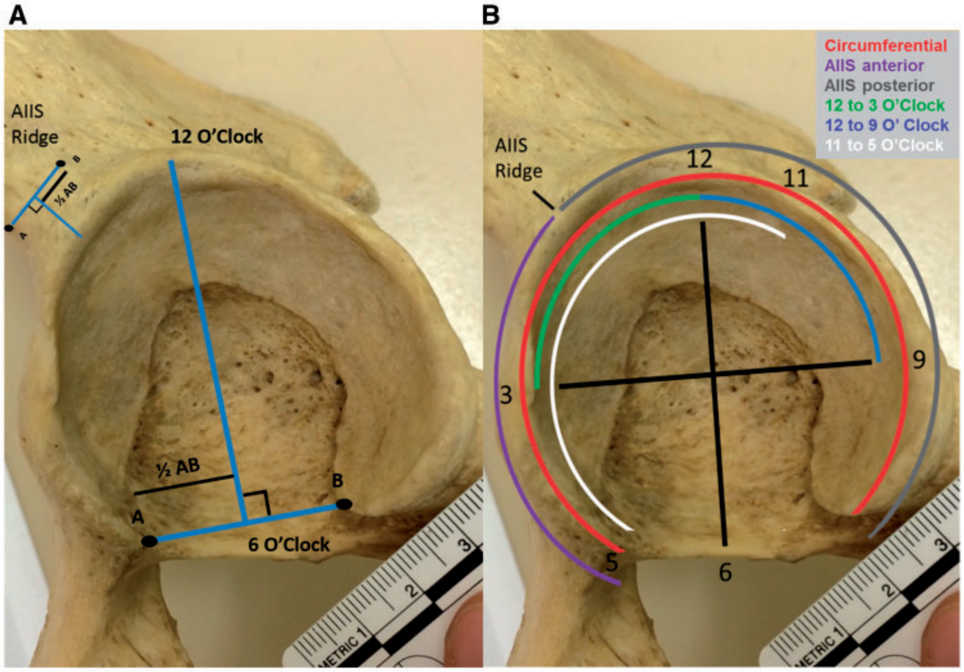

Fig. 1. (**A**) The midpoint of the acetabular notch was measured and referenced as the 6 o'clock position with a point 180° to this as the 12 o'clock position. The point in which the midpoint of the AIIS transverse ridge intersected the acetabular rim was used for AIIS arc measurements. (**B**) Examples of specific rim lengths measures. Each of six measurements highlighted by rim arc in different color.

AIIS ridge posteriorly to the acetabular notch, (iv) 12–3 o'clock, (v) 12–9 o'clock and (vi) 11–5 o'clock. In the multiple regression analysis, multicollinearity was assessed as negative based on variance inflation factor <10 and coefficient tolerance >0.1, normal probability plots of the regression standardized residual were inspected for normality, and the lack of any undue influence from outliers was confirmed with a Cook's distance <1.

RESULTS

Rim length measurements were made for 143 sets of acetabula. Of these, 90 (63%) were male, and 53 (37%) were female. The average age of males and females was 57.6 (range 18–78) and 48.8 (range 27–77), respectively. Ethnicity data were available for 139 of 143 specimens. Forty-nine (35%) specimens were African-American, and 90 (65%) were Caucasian. The average acetabular rim length for all six measurements was essentially similar between right and left acetabula (<2 mm difference in averages). There was excellent interrater reliability with ICC values of 0.953, 0.930, 0.958, 0.857, 0.913 and 0.951 for circumferential, AIIS-anterior, AIIS-posterior, 12–3 o'clock, 12–9 o'clock and 11–5 o'clock measurements, respectively.

The average acetabular rim length for the six measurements for males for circumferential, AIIS-anterior, AIIS-posterior, 12–3 o'clock, 12–9 o'clock and 11–5 o'clock were 15.8, 4.2, 11.7, 4.9, 4.7 and 9.5 cm, respectively. Similarly, those measurements for females were 13.7, 3.7, 10.0, 4.3, 4.1 and 8.3 cm (Fig. 2). All six measurements were significantly larger for males ($P < 0.001$ for all measurements). Mean, minimum and maximum values, and 95% confidence intervals are presented in Table I.

Multiple regression analyses showed a strong correlation between female sex and rim size for all six measurements, even with femur/tibia length versus height factored out in the multiple regression analysis, with standardized betas ranging from 0.451 to 0.620 ($P < 0.001$ for all measurements) (Table II). With respect to height, there was a significant relationship found for five of the six measurements with the exception of AIIS anteriorly to the acetabular notch ($P = 0.54$). Standardized beta values ranged from 0.246 to 0.337 ($P < 0.001$ for the five significant measurements). There was a modest significant relationship between age and the AIIS-posterior and 12–9 o'clock measurements only. This relationship was not found in the separate regression model utilizing leg length in place of height and is not likely clinically significant. The same significant relationship was found for leg lengths in five of six measurements excluding AIIS anteriorly to the acetabular notch ($P = 0.281$). No significant relationships between ethnicity and rim size for any of the six measurements were found. The results of the multiple regression analysis are summarized in Table II.

DISCUSSION

It is often necessary to work around the bony acetabular rim when performing rim trim, labral fixation, subspine decompression and/or labral reconstruction [3, 4, 25–29]. A recent anatomic study has contributed greatly to our understanding of peri-acetabular soft tissue structures, including defining labral height and width, tendinous footprints and linear distances between anatomic landmarks around the acetabular rim [30]. While this study provided important information that may be useful in constructing the appropriate height and width of the labral soft tissue graft, it did not investigate labral lengths or the bony acetabular rim that serves as the footprint for labral graft fixation. To the best of the authors' knowledge, no previous studies have documented the circumferential length of the acetabular rim or segmental rim arc lengths in the clinically relevant areas where the labral graft spans during labral reconstruction. One of the aims of this study was to define these normative bony rim length values to serve as a reference point in labrum reconstruction surgery. We found the overall circumferential rim lengths in this study averaged 15.8 and 13.7 cm for males and females, respectively. Most labral damage occurs in the anterior superior quadrant (∼12–3 o'clock) [31, 32] and we segmented the acetabular rim by this common arc. We also included the 12–9 and 11–5 o'clock arcs as work is occasionally needed in these areas. As the AIIS is frequently used as a landmark during arthroscopic decompression, two hemispheric measurements were included from the AIIS anteriorly and posteriorly to the acetabular notch [25–27] (Fig. 2). Mean rim lengths for these clinically relevant rim arcs are presented in Table I.

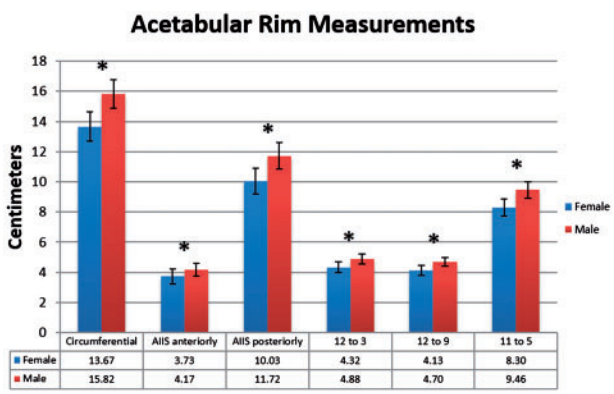

Fig. 2. Circumferential and segmental rim lengths for males versus females. All values displayed in centimeters. Asterisks (*) indicate P values <0.001.

When analyzing the independent variables on multiple regression analysis, gender was the strongest predictor of rim length and was significant for all six measurements. Moreover, the weight of influence of gender on rim length was preserved in each regression model, when the effect of limb length versus height was also factored. These findings are not unexpected given the known differences in male and female acetabulum anatomy and FAI morphology [16–18, 33, 34]. In addition, height had a significant correlation with rim length in five of the six measurements. Leg length, in addition to height, was analyzed as the height

Table I. Values for circumferential and segmental rim lengths for males and females

	Circumferential	*AIIS anteriorly*	*AIIS posteriorly*	*12–3*	*12–9*	*11–5*
Males						
Mean	15.82	4.17	11.72	4.88	4.70	9.46
95% CI	(15.69–15.95)	(4.11–4.23)	(11.61–11.84)	(4.83–4.92)	(4.66–4.74)	(9.38–9.53)
Minimum	13.01	3.02	9.67	4.12	4.15	8.17
Maximum	18.72	5.61	13.99	5.61	5.53	11.00
Females						
Mean	13.67	3.73	10.03	4.32	4.13	8.30
95% CI	(13.53–13.81)	(3.66–3.80)	(9.91–10.15)	(4.27–4.37)	(4.08–4.17)	(8.21–8.38)
Minimum	12.20	2.91	8.84	3.82	3.48	7.45
Maximum	15.85	4.92	12.18	5.18	5.14	9.66

Mean values and ranges for circumferential and segmental rim lengths for males and females. 95% confidence intervals included. All values displayed in centimeters.

Table II. Multiple regression analysis

Model	*Variable*	*Unstandardized β*	*Standardized β*	P *value*
Circumferential				
	Female	−17.14	−0.620	**<0.001**
	Age	0.066	0.036	0.067
	Black	−2.146	−0.077	0.058
	Height	0.359	0.246	**<0.001**
AIIS Anterior				
	Female	−4.145	−0.451	**<0.001**
	Age	0.002	0.006	0.924
	Black	−0.632	−0.068	0.257
	Height	0.02	0.041	0.54
AIIS posterior				
	Female	−12.911	−0.563	**<0.001**
	Age	0.075	0.105	**0.020**
	Black	−1.338	−0.058	0.182
	Height	0.324	0.267	**<0.001**
12–3 o'clock				
	Female	−3.976	−0.476	**<0.001**
	Age	0.024	0.094	0.055
	Black	0.452	0.054	0.257
	Height	0.14	0.318	**<0.001**
12–9 o'clock				
	Female	−4.133	−0.518	**<0.001**
	Age	0.028	0.114	**0.012**
	Black	−0.581	−0.072	0.1
	Height	0.129	0.307	**<0.001**
11–5 o'clock				
	Female	−8.597	−0.555	**<0.001**
	Age	0.028	0.057	0.176
	Black	0.216	0.014	0.737
	Height	0.276	0.337	**<0.001**

P values <0.05 indicated in bold.

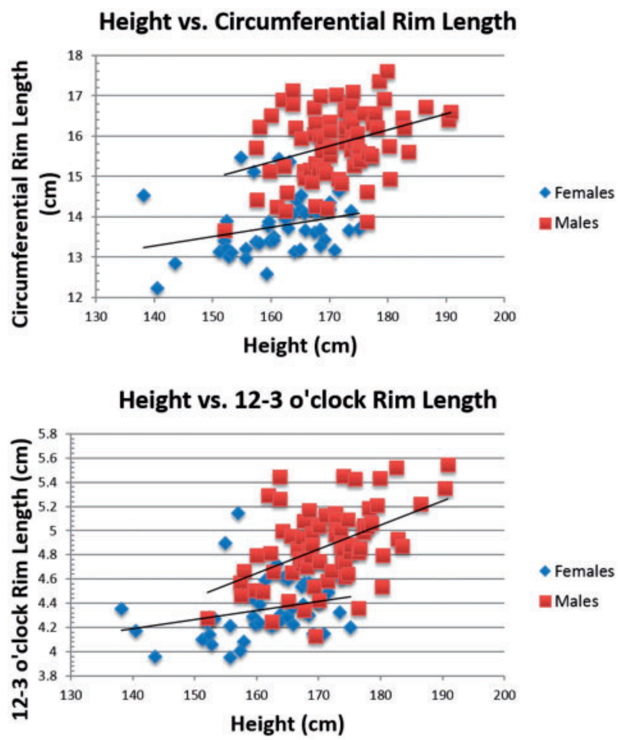

Fig. 3. Circumferential and 12–3 o'clock segmental rim lengths for males and females as a function of height.

measurements were obtained nearly 100 years ago with unverifiable methodology. Multiple regression analysis with leg length instead of height showed that leg length was a significant variable in all instances where height was significant. In addition, the Pearson correlation between height and leg length was 0.89, furthering confidence in the accuracy of the historical height data. Figure 3 represents expected circumferential and 12–3 o'clock segmental rim length measurements for males and females with respect to height. These data help to estimate further the rim length measurements for a given patient based on height and gender data.

Labral reconstruction is gaining greater interest and traction for situations when labral tissue is not amenable to repair. Although debated, current indications include revision procedures with labral deficiency or in primary procedures where the labral tissue is too small (<3 mm), too large (>9 mm) or of poor quality for primary repair [29]. Several techniques are described for labral reconstruction. All involve measuring the length of the prepared acetabular rim using suture length or using an instrument, typically a burr or elevator, of known size to incrementally measure the defect to determine the appropriate graft size [12–14, 35]. However, the graft length must be perfect, and as the size of the labral defect increases, this can be more challenging. If there is graft length and defect size mismatch, and the graft is too tight or too loose, then it can be either challenging to fix to the acetabular rim or it can be difficult to achieve a suction seal between the graft and the femoral head. Either situation is suboptimal. Labral reconstruction techniques might be met with greater success if there was a more reliable way to determine appropriate graft length. With our current lack of appropriate instrumentation to make more precise measurements of the defect size, this study contributes great value. It offers a way to serve as a reference point for the intraoperative measurement to ensure it is both reasonable and accurate. This may assist is estimating an appropriate length graft whether selecting an allograft from the tissue bank or harvesting autograft. This information can help minimize the potential for defect and graft length mismatch and help increase intraoperative efficiency, thus allowing the surgeon to more reliably recreate the seal between the graft and the femoral head.

There are several limitations to this study. First, these measurements are averages across the subset of the population studied. It must be recognized that a wider range of rim lengths within a larger population is possible. In addition, this subset of specimens studied had a rather homogenous ethnicity. Based on these data, there did not seem to be any clinically significant difference between rim length among African-American and Caucasian specimens. We cannot predict if these observations would hold true across all ethnicities in a more diverse population. Second, we determined the 6 o'clock position to be the midpoint of the acetabular notch, which would be spanned by the transverse acetabular ligament *in vivo*. Philipon *et al.* [30] recently validated the reproducibility of the superior edge of the Psoas U at the 3 o'clock position and suggest using this landmark as the reference point for the clock face given the difficulty in accurately determining the midpoint of the transverse acetabular ligament arthroscopically. Given the complete exposure of the entire acetabulum in our bony specimens, we felt confident using the previously described method by identifying the midpoint of the acetabular notch as the 6 o'clock position. While not specifically recorded in this study, the superior edge of the Psoas U did appear to correlate with the 3 o'clock position. Finally, the study uses height and leg length data from a cohort of American individuals from nearly 100 years ago. One must keep in mind that the contemporary population is likely slightly taller than the study population. American height has increased by ∼5 cm since the beginning of the 20th century [36, 37]. Although unlikely, it is possible that the relationship between height and acetabulum rim length has also changed over time.

Much has been studied regarding peri-acetabular and labral anatomy, but no prior study has performed a quantitative investigation of acetabular rim lengths. Using a large osteologic collection, we established normative values for circumferential and segmental acetabular rim lengths. Key differences between male and female acetabular rim lengths were delineated. Acetabular rim length for males was significantly greater than that for females. Age and ethnicity was not a statistical predictor of rim length. In addition, height appears to correlate with acetabular rim length. These findings contribute to our overall understanding of hip anatomy by establishing normative reference values of acetabular rim lengths that may be referenced by surgeons performing labral reconstructions. While this study provides a general guideline of rim lengths, final surgical decisions should be made on an individual basis considering the intraoperative findings and the specific pattern of labral deficiency.

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CONFLICT OF INTEREST STATEMENT

None declared.

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