

## Acetabular Wall Indices Help to Distinguish Acetabular Coverage in Asymptomatic Adults With Varying Morphologies

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### Abstract

**Background** The anterior wall index (AWI) and posterior wall index (PWI) have been proposed to quantify anterior and posterior acetabular coverage using AP pelvic radiographs. However, these indices have only been reported in symptomatic patients with apparent pathomorphologies (dysplasia, overcoverage, and retroversion) undergoing osteochondroplasty or reorientation osteotomy.

**Questions** (1) What are the ranges for AWI and PWI from measurements obtained on AP pelvic radiographs of asymptomatic senior athletes with well-functioning hips? (2) Is there a difference between the AWI and PWI in asymptomatic athletes with acetabular morphology consistent with acetabular dysplasia, overcoverage, and retroversion when compared with asymptomatic hips that

do not meet the radiographic definitions for those morphologies (controls)?

**Methods** Five hundred five athletes (998 asymptomatic native hips) were independently evaluated by two readers on AP pelvic radiographs for AWI and the PWI after excluding hips with prior surgery, inadequate radiographs, or poor function (modified Harris hip score < 80). Hips with a lateral center-edge angle (LCEA)  $\geq 20^\circ$  and  $\leq 38^\circ$  and without acetabular retroversion, based on a positive crossover sign, were used as controls. Hips were categorized as developmental dysplasia of the hip (DDH; undercoverage) if the LCEA was < 20°. Finally, overcoverage was defined as an LCEA > 38°. The mean age of the athletes was 67 years (range, 50–91 years) and 55% were men. Linear generalized estimating equation regression was used to compare each individual diagnosis (DDH, retroversion, overcoverage) with the controls for both AWI and PWI adjusting for age and sex.

**Results** The mean AWI in the study population was 0.36 (range, -0.02 to 0.91). The mean PWI was 1.13 (range, 0.12–1.74). The mean AWI and PWI in controls (n = 740) was 0.35 (range, -0.02 to 0.91) and 1.13 (range, 0.64–1.70), respectively. There were 25 (3%) with DDH in whom the mean AWI was 0.26 (range, 0.05–0.5) and the mean PWI was 1.03 (range, 0.71–1.3). There were 112 (11%) retroverted hips in whom the mean AWI was 0.42 (range, 0.1–0.89) and PWI was 1.02 (range, 0.61–1.5). There were 121 (12%) overcovered hips in whom the mean AWI was 0.43 (range, -0.18 to 0.85) and PWI was 1.22 (0.12–1.74). The AWI in the control hips was no different than that of DDH hips ( $\beta$  -0.06; 95% confidence interval [CI], -0.12 to 0.002;  $p = 0.059$ ) but was found to be lower than retroverted hips ( $\beta$  0.08; 95% CI, 0.04–0.11;  $p < 0.001$ ) and overcovered hips ( $\beta$  0.05; 95% CI, 0.03–0.08;  $p < 0.001$ ). The PWI in control hips was greater than

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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that of DDH hips ( $\beta -0.08$ ; 95% CI,  $-0.14$  to  $-0.02$ ;  $p = 0.013$ ) and retroverted hips ( $\beta -0.07$ ; 95% CI,  $-0.11$  to  $-0.04$ ;  $p < 0.001$ ) but was less than overcovered hips ( $\beta 0.07$ ; 95% CI,  $0.04$ – $0.10$ ;  $p < 0.001$ ).

**Conclusions** The measurements of AWI and PWI in well-functioning, asymptomatic hips may be useful in assessing anterior and posterior acetabular coverage because it was able to distinguish between different types of known pathologic morphology. Despite evidence of these morphologic variances, these senior athletes continued to function at a high level. Thus, the identification of morphologic variance was not consistent with signs of pathology, which further supports that early screening of morphology may not predict the development of symptomatic pathology. Future work should focus on comparing these indices for morphologic variance in both symptomatic and asymptomatic hips to determine whether these measurements can be used in identifying problematic hips and as reference ranges for surgical correction.

**Level of Evidence** Level III, diagnostic study.

## Introduction

Acetabular overcoverage (pincer-type impingement), undercoverage (dysplasia), and retroversion have been recognized as common pathomorphologies that may result in degenerative changes of the hip [2, 6, 7, 12, 18]. However, recent reports suggest that some of these common pathomorphologies may actually be normal variants as opposed to sources of pathology [1, 10]. Acetabular coverage has historically been evaluated with plain radiographs and more recently with advanced three-dimensional imaging techniques and computerized measurements off plain films [8, 17, 19, 20]. In this cost-conscious era, the ability to use plain film radiographs to assess acetabular morphology is warranted. It may be challenging to properly diagnose those hip pathomorphologies associated with anterior and posterior coverage with plain film radiography [10, 14, 15]. To better evaluate anterior and posterior coverage, Siebenrock et al. [15] developed measurements on plain films that take into consideration femoral head size and relative anterior and posterior walls to better quantify wall coverage relative to the femoral head diameter.

The advantage of such indices is that the measurements are applicable and comparable regardless of femoral head (and thus patient) size. Additionally, the relative coverage contributed by each wall (anterior wall index [AWI] and posterior wall index [PWI]) can then be used to assess overall acetabular coverage as well as acetabular morphology and orientation. However, Siebenrock et al. [15] only examined a small number of symptomatic patients

with apparent pathomorphologies who had undergone either periacetabular osteotomy or surgical hip dislocation with or without rim trimming. More recently, Tannast et al. [16] provided reference values for acetabular coverage using well-established measurements. However, their population consisted of patients undergoing surgical intervention related to acetabular over- or undercoverage and they lacked an asymptomatic control group. They also reported that their reference values are only applicable to a symptomatic population. Knowledge of the AWI and PWI in asymptomatic adults may improve our understanding of acetabular morphology and help us better understand normal variants that can function asymptotically into the senior years.

Thus, we sought to determine the range of these indices in a large cohort of well-functioning, asymptomatic hips in an active senior population. Specifically, we sought to answer the following: (1) What are the ranges for AWI and PWI from measurements obtained on AP radiographs of senior athletes with well-functioning hips? (2) Is there a difference between the AWI and PWI in asymptomatic athletes with acetabular morphology consistent with common pathomorphologic changes (developmental dysplasia of the hip [DDH], retroversion, or overcoverage) when compared with asymptomatic hips that do not meet the radiographic definitions for those morphologies (controls)?

## Patients and Methods

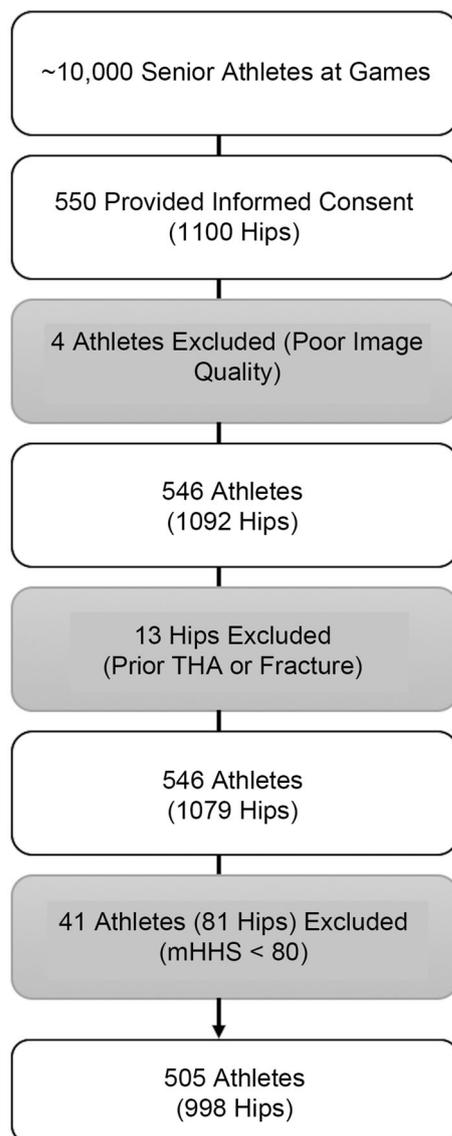
After obtaining approval from the institutional review board (IRB #55673), we performed a cross-sectional study looking at the prevalence of radiographic abnormalities of the hip in senior athletes competing at the 2012 Huntsman World Senior Games in St George, UT, USA. The senior games consist of a variety of sporting events for athletes older than 50 years of age. Senior athletes with well-functioning hips provide a unique opportunity to assess hip morphology in an active population who has survived into the senior years and may help us better understand the normal variants of hip morphology. We have previously reported on the prevalence of femoroacetabular impingement (FAI) and DDH in this population [1]. As part of the games, myriad of health screenings were available in the convention hall to all athletes to encourage improved health. Our research booth was erected in the hall and institutional review board-approved advertising was used both at the booth and in the hall entrance. Of the approximately 10,000 athletes attending the games, 550 presented to the booth and provided informed consent for radiographic evaluation of their hips. No compensation was provided for their participation and no medical advice was given. These athletes also completed a modified Harris hip

score (mHHS) [4]. After excluding hips with prior THA, surgery, trauma, those who had inadequate imaging resulting from artifact, and those with a mHHS < 80 (considered fair to poor [9]), we were able to evaluate 505 athletes (998 hips; Fig. 1) with asymptomatic, well-functioning hips. Forty-five percent of the athletes were women ( $n = 228$ ) and 55% were men ( $n = 277$ ). The mean age was 67 years (range, 50–91 years). In regard to race, 91% were white (458 of 505), 2% black (nine of 505), 2% Asian (eight of 505), 2% other (12 of 505), and 3% (12 of 505) did not respond to this question.

For the radiographic evaluation, two orthopaedic surgeons (LAA, JC) assessed both hips independently. Radiographs were obtained using a mobile digital radiograph system (Viztek, Garner, NC, USA, and Source-Ray,

Inc, Ronkonkoma, NY, USA). Standard techniques were used to control for pelvic tilt and rotation as has been previously described [1]. Two views, pelvic AP and frog-leg lateral radiographs, were performed in the supine position. The radiographic measurements have been previously described by Anderson et al. [1] and included the evaluation of morphologic changes consistent with cam FAI by alpha angle, acetabular overcoverage by acetabular index, and lateral center-edge angle (LCEA) to assess lateral acetabular undercoverage (DDH). Furthermore, evaluation of radiographic evidence of retroversion, where the acetabulum lies at a posterior angle to the sagittal plane, was determined by the presence of a crossover sign and overcoverage (pincer FAI) [13]. A posterior wall sign was also reviewed and only considered positive if both readers considered it positive. Of the 998 hips, 213 (21%) had a positive posterior wall sign, 43 of those also had acetabular retroversion, and nine had DDH. For the purposes of this article, hips were categorized into morphology type based on radiographic measurements and not a clinical diagnosis. Hips were deemed controls ( $LCEA \geq 20^\circ$  and  $\leq 38^\circ$  and without acetabular retroversion), DDH hips ( $LCEA < 20^\circ$ ), retroverted hips (positive crossover sign), or hips with overcoverage ( $LCEA > 38^\circ$ ). Measurements were averaged between the two readers to account for differences. We identified 740 hips (74%) lacking the radiographic signs of any of these morphologic changes and deemed them as controls, 25 hips with DDH (3%), 112 retroverted hips (11%), and 121 overcovered hips (12%). It should be noted that all hips were asymptomatic hips in high-functioning senior athletes. The AWI and PWI radiographic measurements (Fig. 2) were performed as described by Siebenrock et al. [15] where the indices “measure the length of the covered head portion [by the wall] along the head-neck axis and divide this measurement by the radius of the femoral head.” They proposed these measurements as a way to evaluate both anterior and posterior wall coverage relative to the femoral head in addition to the lateral coverage measured by the LCEA.

The concordance correlation coefficient ( $r_c$ ) and a Bland–Altman Analysis were used to assess interrater reliability and interrater agreement between the two readers for both the AWI and the PWI [3, 11]. The effect size for the  $r_c$  was classified as small (0.10–0.29), medium (0.30–0.49), and large ( $\geq 0.50$ ) [5]. The two orthopaedic surgeons assessing the radiographs demonstrated large correlations in the radiographic measures of alpha angle, acetabular index, and LCEA as well as in the crossover sign as an indication of retroversion [1]. For this study, the data demonstrated a large effect for reliability with an  $r_c$  of 0.96 for the AWI and 0.93 for the PWI (Table 1). Additionally, the raters demonstrated very small average differences of < 1.

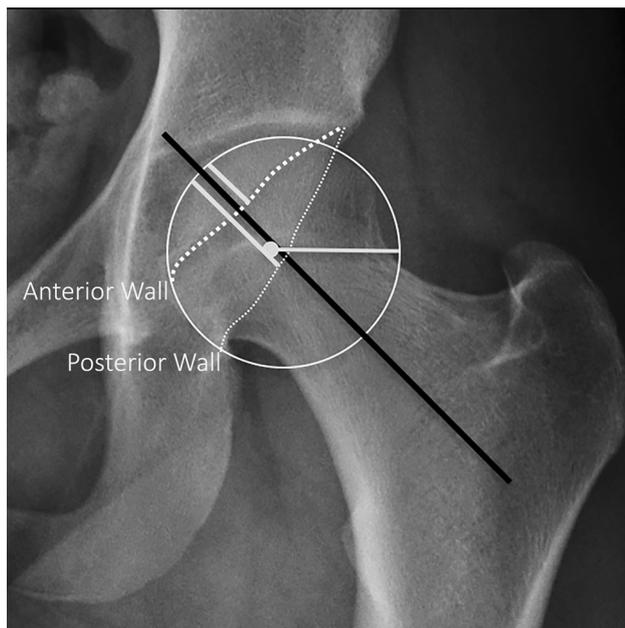


**Fig. 1** This flow sheet demonstrates the attrition of the participants in the study.

Univariable and multivariable linear generalized estimating equation regression was used to compare each individual diagnosis (DDH, retroversion, overcoverage) with controls for both outcomes (AWI and PWI) adjusting for age and sex. Hommel's procedure was used to adjust for multiplicity given that three individual diagnoses were compared with the same control hips. Data are reported as mean  $\pm$  SD for the indices in each group. Significance was assessed at the 0.05 level. Statistical analysis was performed using Stata® Version 14.1 (College Station, TX, USA).

## Results

The mean AWI in the study population was 0.36 (range,  $-0.02$  to  $0.91$ ) and the mean PWI was 1.13 (range,  $0.12$ – $1.74$ ). The mean AWI for control hips was 0.35 (range,  $-0.02$  to  $0.91$ ) and the mean PWI for control hips was 1.12



**Fig. 2** The wall indices are measured by drawing a line from the medial edge of the circle (femoral head) to the anterior and posterior walls. These measurements are then divided by the radius of the femoral head to calculate the AWI (anterior wall measurement) and the PWI (posterior wall measurement).

(range,  $0.64$ – $1.70$ ; Table 2). In control hips, when adjusting for sex, age was not associated with the AWI ( $\beta$   $0.00003$ ; 95% confidence interval [CI],  $-0.001$  to  $0.001$ ;  $p = 0.968$ ) or the PWI ( $\beta$   $-0.001$ ; 95% CI,  $-0.002$  to  $0.001$ ;  $p = 0.217$ ). Furthermore, there was no difference in the AWI between men and women in the control group ( $\beta$   $0.019$ ; 95% CI,  $-0.006$  to  $0.04$ ;  $p = 0.131$ ). Men in the control group had a mean AWI of 0.36 (range,  $-0.02$  to  $0.91$ ) and women had a mean AWI of 0.34 (range,  $-0.02$  to  $0.81$ ). However, men in the control group had a slightly smaller PWI than women ( $\beta$   $-0.05$ ; 95% CI,  $-0.08$  to  $-0.02$ ;  $p = 0.002$ ) with a mean PWI of 1.11 (range,  $0.64$ – $1.70$ ) compared with a mean PWI of 1.15 (range,  $0.67$ – $1.67$ ) in women when controlling for age.

When adjusting for age and sex, the mean AWI in the control hips ( $0.35 \pm 0.015$ ) was not different than that of DDH hips ( $0.26 \pm 0.13$ ) with the numbers available ( $\beta$   $-0.06$ ; 95% CI,  $-0.12$ – $0.002$ ;  $p = 0.059$ ; Table 3). The AWI in control hips was found to be lower than retroverted ( $0.42 \pm 0.16$ ,  $\beta$   $0.8$ ; 95% CI,  $0.04$ – $0.11$ ;  $p < 0.001$ ) and overcovered hips ( $0.43 \pm 0.18$ ,  $\beta$   $0.05$ ; 95% CI,  $0.03$ – $0.08$ ;  $p < 0.001$ ).

When adjusting for age and sex, the PWI in control hips ( $1.13 \pm 0.17$ ) was greater than that of DDH hips ( $1.03 \pm 0.16$ ,  $\beta$   $-0.08$ ; 95% CI,  $-0.14$  to  $-0.02$ ;  $p = 0.013$ ; Table 4) and retroverted hips ( $1.02 \pm 0.15$ ,  $\beta$   $-0.07$ ; 95% CI,  $-0.11$  to  $-0.04$ ;  $p < 0.001$ ), but was smaller than overcovered hips ( $1.22 \pm 0.21$ ,  $\beta$   $0.07$ ; 95% CI,  $0.04$ – $0.10$ ;  $p < 0.001$ ). We attempted to correlate AWI/PWI to the radiographic morphologies but no significant associations were noted.

**Table 2.** Mean (range) of AWI and PWI for DDH, retroverted, and overcovered hips

Diagnosis	Mean AWI (range)	Mean PWI (range)
Normal	0.35 ( $-0.02$ to $0.91$ )	1.13 ( $0.64$ – $1.70$ )
DDH	0.26 ( $0.05$ – $0.5$ )	1.03 ( $0.71$ – $1.3$ )
Retroversion	0.42 ( $0.1$ – $0.89$ )	1.02 ( $0.61$ – $1.5$ )
Overcoverage	0.43 ( $-0.18$ to $0.85$ )	1.22 ( $0.12$ – $1.74$ )

AWI = anterior wall index; PWI = posterior wall index; DDH = developmental dysplasia of the hip.

**Table 1.** Interrater agreement for AWI and PWI

Variable	$r_c$	95% CI	Bland–Altman average difference (SD)	95% limits of agreement	Pearson's $r$
AWI	0.96	0.953–0.963	0.00 (0.046)	$-0.090$ to $0.091$	0.96
PWI	0.93	0.918–0.935	$-0.005$ (0.070)	$-0.142$ to $0.133$	0.93

AWI = anterior wall index; PWI = posterior wall index;  $r_c$  = concordance correlation coefficient; CI = confidence interval.

**Table 3.** Linear GEE regression analysis for anterior wall index

Morphology type	Unadjusted $\beta$ (95% CI)	Adjusted $\beta$ (95% CI)	Multiplicity adjusted p value
DDH	-0.05 (-0.11 to 0.008)	-0.06 (-0.12 to 0.002)	0.059
Retroversion	0.07 (0.04–0.11)*	0.08 (0.04–0.11)*	< 0.001
Overcoverage	0.05 (0.03–0.08)*	0.05 (0.03–0.08)*	< 0.001

\*Significant at  $p < 0.05$ ; GEE = generalized estimating equation; CI = confidence interval; DDH = developmental dysplasia of the hip.

**Table 4.** Linear GEE regression analysis for posterior wall index

Morphology type	Unadjusted $\beta$ (95% CI)	Adjusted $\beta$ (95% CI)	Multiplicity adjusted p value
DDH	-0.06 (-0.13 to -0.009)*	-0.08 (-0.14 to -0.02)*	0.013
Retroversion	-0.08 (-0.11 to -0.04)*	-0.07 (-0.11 to -0.04)*	< 0.001
Overcoverage	0.06 (0.03–0.09)*	0.07 (0.04–0.10)*	< 0.001

\*Significant at  $p < 0.05$ ; GEE = generalized estimating equation; CI = confidence interval; DDH = developmental dysplasia of the hip.

## Discussion

Siebenrock et al. [15] recently proposed anterior and posterior acetabular wall indices as a way to measure relative femoral head coverage by the anterior and posterior acetabular walls. However, they evaluated these indices in symptomatic patients undergoing surgery (34 “dysplastic acetabulum,” 34 “deep acetabulum”) and only included 19 “normal” or control hips. The authors emphasized the need to validate these measurements in a population of asymptomatic hips. Thus, we sought to determine the range of these indices in a large group of asymptomatic hips. Despite a population consisting of active senior athletes with asymptomatic hips, we frequently identified morphologic changes consistent with overcoverage, DDH, and retroversion. Given the high function of the patients evaluated, it appears that these changes may be normal variants that are often able to survive into the senior years without pathologic changes. Similarly, Larson et al. [10] reported that 37% of asymptomatic hips in their study presented with radiographic signs of retroversion and/or dysplasia. Our previous study on this population reported that 83% had radiographic evidence of FAI and 10% had evidence of acetabular dysplasia [1], further supporting the evidence that these morphologic variants are not always pathologic. Thus, cost-effective and efficient radiographic parameters to better understand acetabular coverage are needed. That said, our prior study did show a significant association of FAI and DDH to a lesser degree with the presence of radiographic osteoarthritis in these asymptomatic senior athletes. The indices proposed by Siebenrock et al. [15]

may be useful in improving our ability to assess not only lateral coverage, but also the relative acetabular coverage both anteriorly and posteriorly using plain film radiographs.

There were several limitations in this study that warrant discussion. First, although all of the hips included in the analysis were asymptomatic with regard to preexisting hip pain and function, many hips displayed morphologic variants consistent with DDH, retroversion, and overcoverage. Therefore, we sought to evaluate these variances in well-functioning hips in senior athletes and classify them into radiographic categories based on well-described acetabular morphology classifications ranging from undercovered (DDH, LCEA  $< 20^\circ$ ), overcovered (LCEA  $> 39^\circ$ ), retroverted, and normal (controls). In doing so we have defined our controls as having “normal” acetabular morphology with LCEA between  $20^\circ$  and  $39^\circ$  with no crossover sign. We recognize that this classification may be overly simplistic, but, in general, this definition allows comparison to hips with accepted parameters indicative of acetabular under- and overcoverage. A second limitation, unlike the study by Siebenrock et al. [15], is that we did not have three-dimensional imaging of these hips to serve as comparative data or to facilitate validation of the quantitative metrics provided by the AWI and PWI in this group of patients. However, plain radiographs remain the standard for diagnosing DDH and FAI and frequently are the only imaging obtained by many hip preservation surgeons before surgery, making them an appropriate evaluation tool for this study. Furthermore, the goal of this study was to determine the AWI and PWI by

plain AP pelvic radiographs in a large cohort of asymptomatic hips and thus further imaging would have been unnecessary and difficult to obtain. Additionally, we did not assess for intrarater reproducibility of these indices and thus cannot comment on the reliability in regard to this matter. Finally, given the limited number of DDH hips ( $n = 25$ ) in this study, it is likely we were underpowered to detect a difference between normal hips and DDH hips in regard to AWI and PWI.

This study provides ranges of the AWI and PWI in an asymptomatic active senior population with well-functioning hips (Table 2). Our data improve the understanding that morphologic variance, associated with relative wall coverage to the femoral head diameter, may not predict asymptomatic hip survival late into adulthood because our average-aged patient was 67 years old. This further supports the work of Larson et al. [10] who reported a high prevalence of asymptomatic hips with a positive crossover and/or posterior wall sign using a CT-based method for evaluating normal acetabular coverage. Additionally, if supported by future research, these data may be useful when determining the target goal anterior and posterior wall coverage of the femoral head in rim trimming or periacetabular osteotomy hip preservation surgery. To our knowledge there have been no other reports on wall indices in the asymptomatic hip.

Interestingly, we were able to identify differences between control hips and asymptomatic hips with morphologic evidence consistent with DDH, acetabular retroversion, and acetabular overcoverage. Our data indicated that the AWI in normal hips was lower than the AWI in hips with acetabular retroversion and acetabular overcoverage. This is consistent with the data from Siebenrock et al. [15] who identified that the AWI in hips with normal morphology was less than hips with a “deep” acetabulum. Whereas we chose to separate acetabular retroversion and overcoverage into separate groups, Siebenrock et al. [15] classified “deep” hips as meeting one of two criteria: an LCEA of  $> 39^\circ$  or acetabular fossa medial to the ilioischial line. This difference in categorization may explain why Siebenrock et al. [15] reported a slightly greater AWI (mean, 0.61; range, 0.24–0.89) in deep hips compared with the AWI values in our study for hips with acetabular retroversion or overcoverage (mean, 0.42–0.43). In terms of absolute numbers, the AWI values determined from our study for controls and dysplastic hip morphologies (mean, 0.35 and 0.26) were remarkably similar to those reported by Siebenrock et al. [15] (mean, 0.41 and 0.28), although, as previously noted, we were unable to show a statistical difference in these metrics, most likely as a result of inadequate power.

Our data indicated that the PWI in normal hips was significantly greater than the PWI in hips with DDH and

**Table 5.** Comparison of the current study (senior athletes) and Siebenrock et al. [15] results for AWI and PWI

Hip morphology study	Number	AWI	PWI
Normal			
Senior athletes	740	0.35	1.12
Siebenrock et al.	19	0.41	0.91
DDH			
Senior athletes	25	0.26	1.03
Siebenrock et al.	34	0.28	0.81
Overcoverage			
Senior athletes	121	0.43	1.22
Siebenrock et al.	34	0.61	1.15
Retroversion			
Senior athletes	112	0.42	1.02
Siebenrock et al.	N/A	N/A	N/A

AWI = anterior wall index; PWI = posterior wall index; DDH = developmental dysplasia of the hip; N/A = not available.

acetabular retroversion and significantly less compared with hips with acetabular overcoverage. These data are consistent with clinical observations as well as prior CT-based studies showing that hips with DDH and acetabular retroversion suffer from deficient posterior acetabular coverage, supporting the index as a useful tool [8]. When comparing our data with that of Siebenrock et al. [15], our population of senior athletes demonstrated a higher PWI in normal hips (Table 5), which could be related to our cohort being older (average age 67 years versus average age 31–37 years) than the population reported by Siebenrock et al. [15] and thus having more ossification of the labrum, leading to greater bony coverage.

The measurements of AWI and PWI in well-functioning, asymptomatic hips may be useful in assessing anterior and posterior acetabular coverage because it was able to distinguish between different types of known pathologic morphology. However, despite evidence of these morphologic variances, these senior athletes continued to function at a high level. Thus, the identification of morphologic variance alone was not correlated with signs of pathology in these active asymptomatic seniors, further supporting the notion that early screening of morphology may not predict the later development of symptomatic pathology. Similarly, Larson et al. [10] caution against the use of plain film radiographs as the only source of information when making a diagnosis of pathomorphology of the hip. These indices may be useful as technology advances in guiding surgical correction during rim trimming procedures for focal or general overcoverage or periacetabular osteotomy surgeries for DDH or retroversion. Future work should focus on comparing these indices for morphologic variance in both

symptomatic and asymptomatic hips to determine whether these measurements can be used in identifying problematic hips and as reference ranges for surgical correction.

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