Original Research

Acetabular Morphology and Spinopelvic Characteristics

What Predominantly Determines Functional Acetabular Version?

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Investigation performed at The Ottawa Hospital, Ontario, Canada

Background: In addition to the relative size of the acetabular rim and how the pelvis is positioned in space, the plane in which the acetabular version is calculated also affects its measurement.

Purpose: To determine the relative contribution of pelvic and acetabular characteristics on morphological version (measured relative to the anterior pelvic plane angle [APPA]) and functional version (measured relative to the horizontal table).

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Included were 50 acetabular dysplasia patients and 109 asymptomatic controls. Using image analysis software, morphological parameters of the pelvis and acetabulum were determined from 2-dimensional computed topography: pelvic incidence, pelvic tilt angle, sacral slope, APPA, morphological and functional acetabular versions, and subtended angles (measure of acetabular rim prominence relative to the femoral head center) around the acetabular clockface in 30° increments. Correlation and multivariable regression analyses were performed with morphological and functional version as dependent variables and spinopelvic and acetabular parameters as independent variables.

Results: Morphological version was moderately associated with differences between anterior and posterior subtended angles ($R = 0.68$ [$P < .001$] and $R = 0.57$ [$P < .001$] for differences at 165° and 15° and 135° and 45°, respectively). Functional version was moderately associated with pelvic tilt angle ($R = 0.56$; $P < .001$) and the difference in subtended angles between anterior and posterior rims ($R = 0.61$ [$P < .001$] and $R = 0.50$ [$P < .001$] for differences at 165° and 15° and 135° and 45°, respectively). Multivariate analysis revealed a good model for predicting morphological version ($R^2 = 0.44$; $P < .01$) and functional version ($R^2 = 0.58$; $P < .01$). Subtended angle difference between 165° and 15° ($B = 0.36$ [95% CI, 0.24-0.49]; $P < .001$) was most strongly related to morphological version, and pelvic tilt angle ($B = 0.57$ [95% CI, 0.46-0.68]; $P < .001$) was most strongly related to functional version.

Conclusion: Functional acetabular version was influenced most strongly by pelvic tilt angle rather than the relative prominence of the acetabular rims. Before determining surgical management for version abnormalities, it would be prudent to assess pelvic mobility and characteristics in different functional positions. In patients with minimal pelvic tilt change dynamically, corrective osteotomy would be the treatment of choice to improve functional version.

Keywords: hip/pelvis/thigh; imaging and radiology general; imaging and radiology computed topography; osteotomy; acetabular version; pelvic tilt

The orientation of the acetabulum is an important determinant of hip joint function. Acetabular version describes the opening of the acetabulum in the transverse plane and can be defined in different ways according to the reference planes used, as described by Murray.[31] Abnormalities in the acetabular version, particularly acetabular retroversion, have been associated with the development of hip pain and early onset of osteoarthritis.[4,12,13] Acetabular radiographic features indicative of version abnormalities include the crossover sign/index, anterior/posterior wall indices, and posterior wall sign. Pelvic features associated with acetabular retroversion include the ischial spine sign and oblique obturator foramina sign.[22,36,45]

A patient's acetabular version at the time of radiographic evaluation (physiological version) is dependent on (1) the

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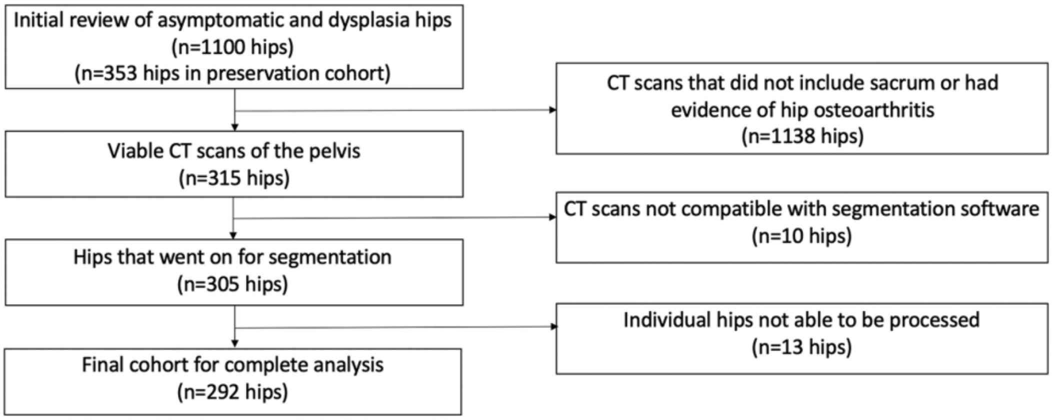

Figure 1. Flow diagram of hip selection process. CT, computed tomography.

anatomy of the acetabulum itself and (2) the relative orientation of the pelvis in space, since acetabular version increases as posterior pelvic tilt angle increases (anterior superior iliac spines rotate posteriorly relative to pubis).[8,10,19] When transitioning from a supine to a standing position, posterior pelvic tilt angle typically increases, which leads to an increase in the physiological version and the posterior acetabular coverage of the femoral head based on radiographic assessments (reference plane is relative to the cassette).[23,34,43,48] However, if the acetabular version is measured in both positions relative to the anterior pelvic plane angle (APPA), the acetabular version would be unaltered, as the reference plane is the pelvis itself (morphological version).[48] An individual's spinopelvic characteristics are reported to have an influence on the difference between physiological (version of the acetabulum relative to horizontal when supine and vertical when standing) and morphological version; Thelen et al[47] found that functional version was greater than morphological version at larger pelvic incidences and lower than morphological version in patients with smaller pelvic incidence.

The relationship between spinopelvic and acetabular characteristics with morphological acetabular version has yet to be elucidated clearly. Both acetabular morphology and spinopelvic parameters have been associated with the development of symptomatic hip disorders, but the degree to which each of these relates to functional acetabular version has not been defined; in other words, is retroversion predominantly a result of abnormal spinopelvic characteristics or secondary to malorientation of the bony acetabulum itself?[6,12,14] In this study, we aimed to (1) characterize the relationship between spinopelvic parameters and acetabular morphological version and (2) determine the relative contribution of the pelvic tilt angle and of the acetabular morphology on morphological and functional acetabular version.

METHODS

This was a retrospective, institutional review board–approved, single-center cohort study. Patients were recruited from a tertiary-referral academic center. To determine morphological correlations, study patients with a wide range of morphology were included. We thus included patients who underwent a periacetabular osteotomy (PAO) in a hip preservation unit and patients who had no hip pathology in their medical records and who underwent computed tomography (CT) scans of the pelvis and hips for reasons unrelated to the hip. In total, 292 hips were included in the final cohort (Figure 1).

Hip Preservation Cohort

All 353 PAOs performed by 1 of the authors (J.W.) between January 2014 and December 2017 were considered eligible for inclusion. Exclusion criteria were inadequate preoperative CT imaging and/or plain radiographs (n = 254) and previous pelvic/hip surgery or aspherical femoral head (n = 2). CT scans that did not include the sacral endplate, and CT scans that were not compatible with the

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Ethical approval for this study was obtained from The Ottawa Hospital (protocol ID#: 20190405-01 H).

segmentation software, were excluded from the analysis. The remaining 97 hips in 50 patients were included in the study. The PAO was performed for a wide range of acetabular dysplasia (ie, lateral undercoverage, retroversion with dysplasia, retroversion without dysplasia, increased acetabular version).

Asymptomatic Cohort

The asymptomatic group (n = 109 CT scans; 195 hips), consisted of patients that had a CT scan of their pelvis and abdomen for a non–hip related pathology. The cohort was identified from the hospital radiological database, and a consecutive series of 550 scans were reviewed. An orthopaedic hip surgery fellow (S.S.) reviewed all CT scans and medical records for the control group and removed 441 scans that had evidence of hip osteoarthritis, hip abnormality, or cases where treatment had been sought previously from an orthopaedic surgeon.

CT-Based Measurements

Each patient underwent a CT scan of his or her whole pelvis from the L5 vertebra to the lesser trochanter of the femur. Positioning of the patient was standardized with the leg internally rotated so that the patella faced upward with no leg abduction or adduction. The protocol used for image acquisition has been described previously.[40,41] A bone algorithm was applied to the CT scans and they were exported in DICOM (Digital Imaging and Communications in Medicine) format to be imported into image analysis software (Version 2.2; ITK-SNAP). A detailed description of the determination of the acetabular and spinopelvic parameters has been described previously[14]; however, a brief outline is provided below.

Acetabular Parameters. First, the anterior pelvic plane (APP) was determined by fitting a plane through the left and right anterior superior iliac spines and the midpoint of the pubic tubercles. The APPA was then determined as the angle between the APP and the horizontal plane. Acetabular inclination was determined by first defining the acetabular rim plane (ARP), which is determined by selecting numerous points along the acetabular rim and calculating a least squares best-fit plane based on these selected points.[26] Acetabular inclination was then calculated as the angle between the ARP and the vertical plane after projecting into the coronal plane.[26,31] The hip joint center (HJC) was determined by a least squares best-fit sphere of the subchondral segment of the acetabulum, where the radius of the sphere represents the size of the acetabulum. The acetabular depth was determined from the perpendicular distance from the ARP to the best-fit sphere of the acetabular bearing surface.

Based on validated techniques,[7,14] subtended angles around the acetabular clockface were determined using the HJC, an axis joining the left and right HJCs, and rim points. Subtended angles represent the degree of femoral head coverage provided by the acetabulum. As the subtended angle increases, the amount of femoral head coverage also increases. Previously, the ARP had been used to determine the subtended angles around the acetabular clockface but this had a confounding effect as it is dependent on acetabular version.[7,14,24] Therefore, in this study, the HJCs were used a reference for calculation of the subtended angles; this method has previously been described by Larson et al.[24] Similar to previous studies, subtended angles were determined around the weightbearing surface of the acetabular clockface, beginning at the anterior to superior to posterior locations: 15°, 45°, 75°, 105°, 135°, and 165° (Figure 2).[8,14] The reference 0° orientation was defined by the APP. The subtended angle was defined as the 3-dimensional angle between the HJC axis and a line connecting the HJC to the rim points and was interpolated to each of these locations. We felt the 30° increments in locus were necessary to obtain enough points at satisfactory distance and symmetrical locations in the anteroposterior acetabular clockface to determine coverage.

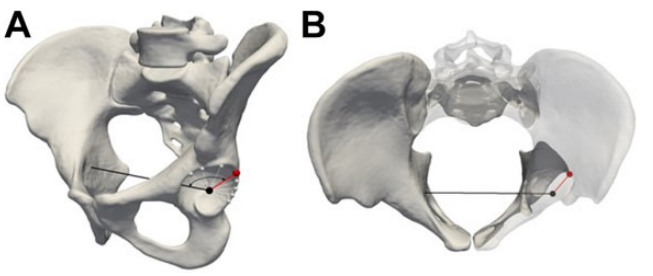

Figure 2. Calculation of the subtended angles from lines connecting the hip joint center and rim points. (A) Oblique lateral where red line joins hip joint center to rim point and black line joins the hip joint centers. Angle represents the subtended angle. (B) Oblique axial to demonstrate the subtended angle as a nominal 2-dimensional angle.

To determine the difference in the coverage of the anterior and posterior acetabular rims, we subtracted the anterior subtended angles from the posterior angles closest to the equator (165° and 15° loci) and at the superior aspect of the joint (135° and 45° loci). Initially, the APP was used as the reference (0°) orientation, following which the orientation was calculated relative to the table, where the CT coordinate system (y-axis) defined 0° orientation.

Anatomic acetabular version was calculated in relation to 2 separate planes. First, morphological acetabular version was the acetabular anteversion relative to the APPA (APP plane defined as zero). Second, functional acetabular version was calculated as the acetabular orientation relative to the radiographic table or horizontal. A depiction of how morphological and functional versions relate is presented in Figure 3. The difference between functional and morphological versions was indicated as Δ_{Version}.

Spinopelvic Parameters. All spinopelvic parameters are represented in Figure 4 and were determined based on previously described methods.[25] The line connecting the HJC of both hips represents the bicoxofemoral axis. Pelvic incidence could then be determined as the angle between the bicoxofemoral axis and the perpendicular from the midpoint of the superior sacral endplate. Sacral slope was calculated as the angle between the sacral endplate and the

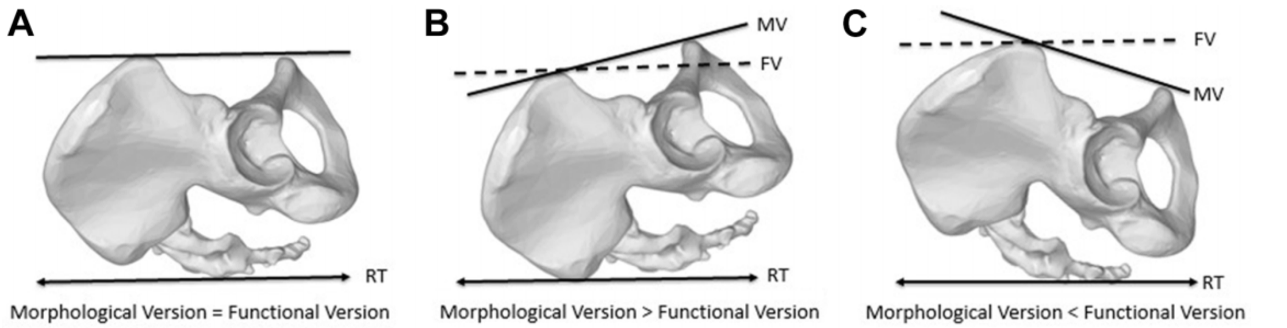

Figure 3. Relationship between MV and FV at (A) neutral, (B) backward, and (C) forward pelvic tilt. RT shown to be parallel to the FV of the pelvis. FV, functional version; MV, morphological version; RT, radiographic table.

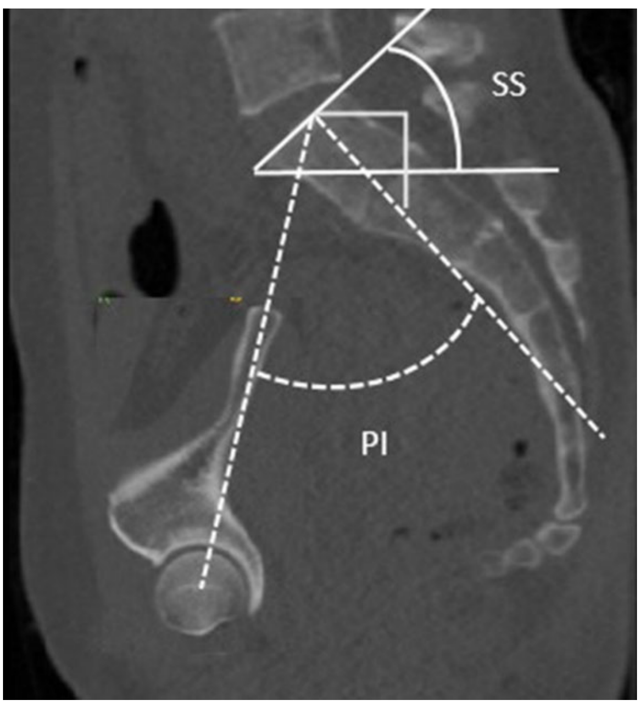

Figure 4. Hip and sacrum projected into a common sagittal plane to show the calculation of the spinopelvic parameters. PI, pelvic incidence; SS, sacral slope.

horizontal. Pelvic tilt angle was determined by subtracting the sacral slope from the pelvic incidence.

Interobserver Reliability

A single observer (Z.D.) blinded to patient identity performed all measurements. Although a single observer was used, the same technique had been utilized previously and found to have high interobserver reliability (intraclass correlation coefficient [ICC], 0.9-0.95; $P < .001$).[14] A total of 31 cases were repeated by the single observer, and the ICC for intraobserver reliability ranged from 0.93 to 0.96 ($P < .001$).

TABLE 1
Descriptive Cohort Statistics

	Overall (N = 292 hips)	Asymptomatic (n = 195 hips)	Hip Preservation (n = 97 hips)
Age, y, mean ± SD	25 ± 6.4	23 ± 3.9	29 ± 8.4
Sex, % female	63.6	70.5	61.8

Statistical Analysis

Analysis was performed using SPSS Statistics, Version 26 (IBM). Differences between groups were assessed using nonpaired Student *t* tests, or paired *t* tests for paired readings. Chi-square tests were used for categorical data. Spearman rho (R) was used to determine correlation coefficients for ordinal or nonparametric data, and Pearson coefficients were used for parametric data. Anatomic parameters that were found to correlate with function and morphological version were used as independent variables in a stepwise multivariate logistic regression analysis to determine the effect magnitude on the resultant morphological and functional version. Beta coefficients were utilized to demonstrate the amount of effect each independent variable had on the dependent variable. Significance level was set at $P < .05$.

RESULTS

The mean age of the overall cohort was 25 ± 6.4 years (range, 16-52 years), and almost two-thirds of the hips were female (n = 187; 64%). There were significantly more male patients in the asymptomatic group (n = 94; 48%) compared with the dysplasia group (n = 11; 11%) ($P < .001$), and the asymptomatic group was significantly younger (23.0 ± 3.9 years) compared with the hip preservation cohort (29.3 ± 8.4 years) ($P < .001$). Participant demographics are presented in Table 1.

Acetabular parameters for the entire cohort are presented in Table 2. Compared with the asymptomatic cohort, the preservation cohort had significantly higher APPA

($P < .001$) and lower functional version ($P < .04$) and $\Delta_{Version}$ ($P < .001$). Overall, morphological version (18.2° ± 9.0°) was greater than functional version (14.7° ± 9.6°) ($P < .05$). The correlation between morphological and functional version was $R = 0.77$ ($P < .001$). Figure 5 represents the differences between morphological and functional version. The mean $\Delta_{Version}$ was –3.4° ± 6.1°. The mean acetabular depth was 19.5 ± 11.2 mm, and the subtended angles varied along the different acetabular clockface loci (Table 2, Figure 6). The subtended angles were greater along the superior and superoposterior aspect of the acetabular clockface (loci: 90°-130°).

Morphological and functional version were assessed at different ranges of pelvic incidence. Morphological version was 12.0° ± 7.6° at pelvic incidences <44°, 20.1° ± 8.4° at pelvic incidences between 44° and 62°, and 21.5° ± 9.9° at pelvic incidences >62°. Functional version was 10.8° ± 7.2° at pelvic incidences <44°, 17.5° ± 7.7° at pelvic incidences between 44° and 62°, and 23.5° ± 9.2° at pelvic incidences >62°. No differences were found between morphological and functional version at these different pelvic incidences.

The correlations between morphological or functional acetabular version with spinopelvic parameters and acetabular characteristics are presented in Figure 7. Morphological version was weakly correlated with APPA ($R = 0.12$; $P = .043$), pelvic incidence ($R = 0.27$; $P < .001$), and pelvic tilt angle ($R = 0.27$; $P < .001$) and moderately correlated with differences between anterior and posterior subtended angles at the 165° and 15° loci ($R = 0.68$; $P < .001$) and at the 135° and 45° loci ($R = 0.57$; $P < .001$). Functional version was weakly correlated with pelvic incidence ($R = 0.38$; $P < .001$) and moderately correlated with pelvic tilt angle ($R = 0.56$; $P < .001$) and with the difference in subtended angles between anterior and posterior rims at the 165° and 15° loci ($R = 0.61$; $P < .001$) and at the 135° and 45° loci ($R = 0.50$; $P < .001$). Functional version was also correlated negatively with APPA ($R = –0.46$; $P < .001$). The $\Delta_{Version}$ was due to the different plane of measurement used and was thus correlated strongly with APPA ($R = 0.9$; $P < .001$);

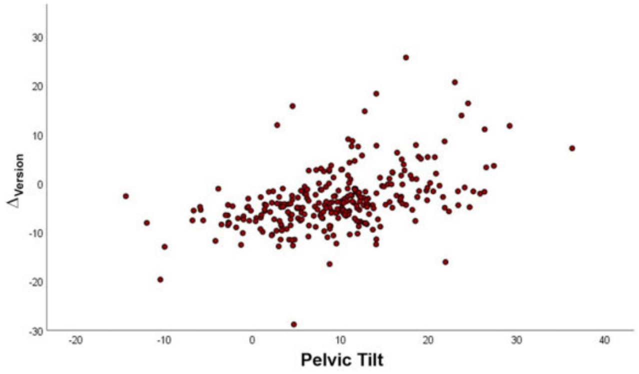

Figure 5. Differences between morphological and functional version as per pelvic tilt.

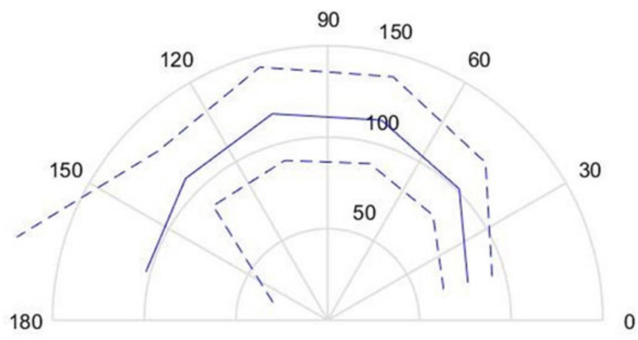

Figure 6. Polar plot for subtended angles around the acetabular rim for the entire cohort. The solid line represents mean; the dashed lines represent 95% CI.

TABLE 2
Comparison of Acetabular and Spinopelvic Parameters Between Study Groups[a]

	Overall (N = 292 hips)	Asymptomatic (n = 195 hips)	Hip Preservation (n = 97 hips)	*P*
APPA (degrees)	5.4° ± 7.2°	3.3° ± 7.1°	9.5° ± 5.4°	**<.001**
Acetabular depth (mm)	19.5 ± 11.2	20.2 ± 13.3	18.1 ± 4.6	.055
Morphological version (degrees)	18.2° ± 9.0°	19.0° ± 8.6°	16.7° ± 9.6°	**.04**
Functional version (degrees)	14.7° ± 9.6°	16.5° ± 9.0°	11.0° ± 9.6°	**.001**
$\Delta_{Version}$ (degrees)	–3.4° ± 6.1°	–2.4° ± 6.1°	–5.5° ± 5.6°	**.001**
Pelvic incidence (degrees)	50.3° ± 11.3°	49.5° ± 9.8°	52.0° ± 13.6°	.11
Pelvic tilt (degrees)	9.5° ± 7.7°	10.0° ± 7.4°	8.3° ± 8.2°	.88
Sacral slope (degrees)	40.8° ± 8.9°	39.4° ± 7.6°	43.6° ± 10.5°	**<.001**
Subtended angle				
At 15°	79.1° ± 7.0°	80.0° ± 6.2°	75.9° ± 8.3°	**.001**
At 45°	101° ± 10.3°	105° ± 8.9°	94.8° ± 10.0°	**<.001**
At 75°	113° ± 12.5°	118° ± 11.5°	107° ± 11.2°	**<.001**
At 105°	117° ± 13.5°	121° ± 10.2°	108° ± 15.2°	**<.001**
At 135°	110° ± 10.8°	112° ± 8.0°	104° ± 13.2°	**<.001**
At 165°	100° ± 8.4°	102° ± 6.5°	96.3° ± 10.6°	**<.001**

[a]Data are reported as mean ± SD. Bold *P* values indicate statistically significant difference between study groups ($P < .05$). APPA, anterior pelvic plane angle.

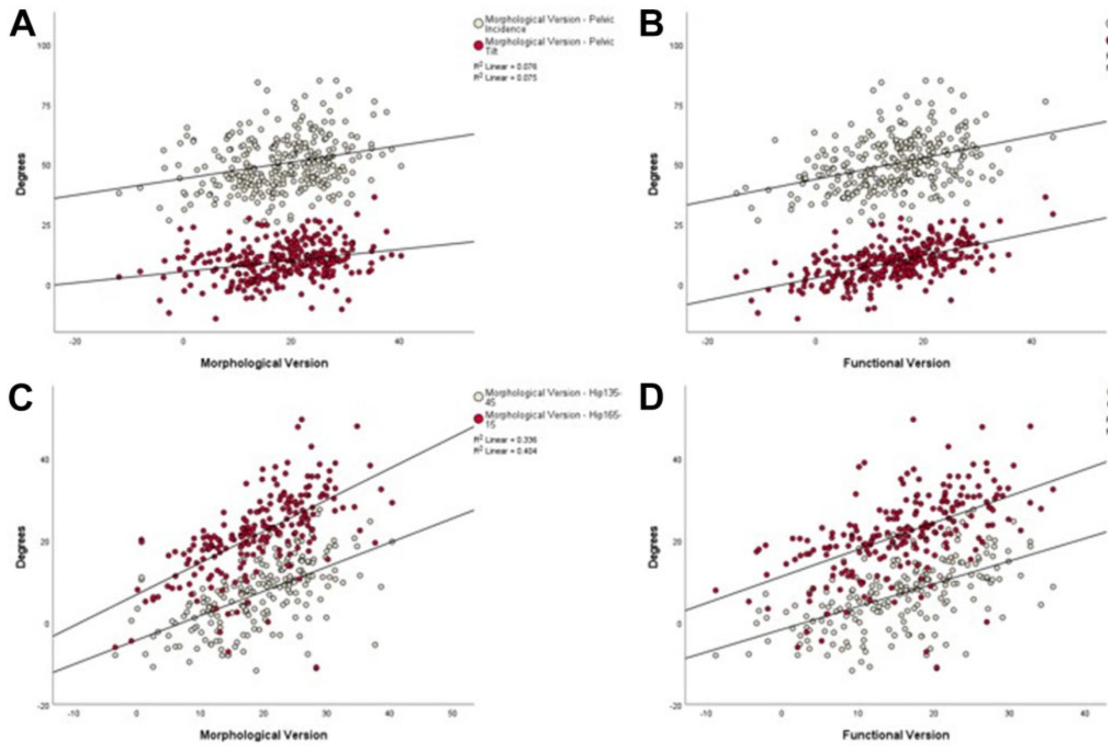

Figure 7. Scatter plots demonstrating correlation between pelvic incidence and pelvic tilt with (A) MV and (B) FV and between subtended angle differences at 45° and 135°, and 15° and 165°, with (C) MV and (D) FV. FV, functional version; MV, morphological version.

Δ_{Version} was also correlated moderately with pelvic tilt angle ($R = 0.48$; $P < .001$) and weakly with pelvic incidence ($R = 0.18$; $P < .001$).

Variables selected for multivariate regression analysis included pelvic tilt angle, difference in subtended angles at 135° and 45°, and difference in subtended angles at 165° and 15°. Inclusion of these variables created good predictive models of morphological ($R^2 = 0.44$; $P < .01$) and functional version ($R^2 = 0.58$; $P < .01$). For morphological version, subtended angle difference between 165° and 15° had the greatest beta coefficient ($B = 0.36$ [95% CI, 0.24-0.49]; $P < .001$), followed by subtended angle difference between 135° and 45° ($B = 0.24$ [95% CI, 0.085-0.39]; $P = .002$) and pelvic tilt angle ($B = 0.13$ [95% CI, 0.004-0.25]; $P = .044$). For functional version, pelvic tilt angle had the greatest beta coefficient ($B = 0.57$ [95% CI, 0.46-0.68]; $P < .001$), followed by subtended angle difference between 135° and 45° ($B = 0.32$ [95% CI, 0.18-0.45]; $P < .001$), and then subtended angle difference between 165° and 15° ($B = 0.20$ [95% CI, 0.086-0.31]; $P = .001$).

DISCUSSION

In this anatomic study of a large number of patients, including both symptomatic and asymptomatic hips, we were able to calculate a number of anatomic features that enabled us to uncouple the relationship between spinopelvic characteristics and acetabular version. Unsurprisingly, the morphological anteversion was dependent primarily on the acetabular morphology and the relative prominence of the anterior and posterior rims. The morphological anteversion showed weak correlations with pelvic incidence and APPA that characterize sagittal pelvic morphology, suggesting a weak developmental interaction between the growing acetabular axial characteristics and sagittal pelvic characteristics. However, it is arguable that the physiological anteversion is more important, as it is the position of the acetabulum in space in different functional positions. The most important factor in what determined functional version, thus what the acetabulum looks like during radiographic assessment, was the pelvic tilt angle ($B = 0.57$), followed by the relative size of the acetabular rims ($B = 0.32$). This has important implications when evaluating patients and considering optimal treatment. It is important to assess whether the functional tilt of the pelvis, and the version, increases in different positions (eg, transitioning from supine to standing) and whether it can be improved with nonoperative measures. However, it is likely that one's pelvic tilt angle cannot be altered much, as previous studies have reported that functional pelvic tilt angle does not change after successful PAO in both retroversion and dysplasia cases (ie, absent compensatory mechanisms).[16,37] We would thus argue that it is the functional version that has to be accounted for and treated, and that one's spinopelvic parameters play an important role as primary determinants of the functional version.

Spinopelvic parameters are being studied increasingly for their effect on acetabular characteristics and the development of symptomatic hip disorders.[8,10-11,19,35] Acetabular version of the hip increases with age and after closure of the triradiate cartilage.[1,15,20,33,46] Similarly, pelvic incidence, an individual's hallmark of sagittal pelvic characteristics, increases with age.[28-29] It is thus possible that a common developmental association exists between the growing pelvis and acetabulum. In this study, pelvic incidence had a weak correlation with morphological ($R = 0.27$; $P < .001$) and functional ($R = 0.38$; $P < .001$) version. Few studies have examined the relationship between spinopelvic parameters and acetabular morphology. Grammatopoulos et al[14] found that pelvic incidence was correlated weakly with acetabular version in a group of asymptomatic and symptomatic CAM hip deformities, and Imai et al[21] found a weak correlation between pelvic tilt angle and acetabular anteversion. However, other groups have found no correlation between pelvic incidence and acetabular version in both normal and pathological hips.[21,38,47] In the current study, the difference between morphological and physiological version was associated with the spinopelvic parameters (pelvic tilt angle and pelvic incidence). This finding is in line with the observations of Thelen et al,[47] who reported a similarly positive association between pelvic incidence and Δ_{version}: when pelvic incidence was less than 44°, functional anteversion was significantly less than morphological anteversion; when pelvic incidence was more than 62°, functional anteversion was significantly greater than morphological anteversion. In our cohort, no differences were found between morphological and functional versions at the pelvic incidence thresholds described by Thelen et al.[47] Thus, further studies are needed to uncouple this relationship.

It is arguable that the functional acetabular orientation is more important than the morphological one. It is thus important to determine which factor predominantly determines functional version. The results of our analysis illustrate that pelvic tilt angle is the most important parameter for functional version, followed by acetabular morphology. The effect of pelvic tilt angle on acetabular morphology has been shown by both imaging and clinical studies. Specifically, acetabular version has been shown to increase with decreasing pelvic tilt angle.[8,19,27,39] Babisch et al[3] found that acetabular version changed by 4° for every 5° of pelvic tilt angle, and Stem et al[42] found that the greatest effect on acetabular version was when pelvic tilt angle was greater than 6°. Pelvic tilt is important in range of motion: increasing pelvic tilt decreases the impingement-free range of motion of the hip.[7] Pelvic tilt angle has shown to be important in the development of symptomatic femoroacetabular impingement and in hip dysplasia.[11,15,18,30] In this study we were able to determine that it is the pelvic tilt angle that predominantly determines the functional orientation of the acetabulum and thus must not be obliterated or unaccounted for, as has been suggested by certain software or certain radiographic descriptions.[44,50] Pelvic tilt angle was correlated positively with pelvic incidence in this study, which is understandable given the algebraic relationship between pelvic incidence and tilt. This is in line with previous observations and has led some to suggest that pelvic incidence is associated with version.[14] However, pelvic incidence was correlated only weakly with functional version. Thus, as this study determines, it is the functional anteversion that is more strongly associated with pelvic incidence secondary to the pelvic tilt angle and its effect on version.

These observations have important implications for physicians looking after patients with hip pathology, as the spinopelvic morphology has to be assessed. In the first instance, it would be important to assess how pelvic tilt changes dynamically for a patient, as this can vary. Furthermore, it would be important for further studies to assess when one's pelvic tilt angle for a given position can significantly alter with targeted physiotherapy, as such changes could prevent impingement or cartilage overload. Studies have shown that pelvic tilt angle changes little after successful PAO for both acetabular retroversion and dysplasia, illustrating that an individual's pelvic tilt angle is unlikely to be compensatory and more likely to be associated with his or her skeletal morphology and overall sagittal balance.[16,39] Pelvic tilt is known to be greater in those individuals with lumbar spine pathology and lumbar back pain.[5] As a result, pelvic tilt has been shown to change significantly with age and to be significantly implicated in hip arthroplasty.[9,17] However, how and whether pelvic tilt changes among individuals as they age from the second to fourth decade of life is, at present, unknown from any prospective studies; most studies have reviewed older cohorts.[2,49] As we found a strong relationship between pelvic tilt and functional acetabular version, future studies should evaluate the association of pelvic tilt changes with lumbar spine aging and pathology and its affect on version and the development of hip pathology. Thus, significant efforts to alter it might not be beneficial. In line with this is the observation that pelvic incidence and tilt was similar between the surgical and asymptomatic cohort in this study, illustrating that no specific compensatory mechanism was identifiable.

The degree of femoral head coverage as measured by the subtended angels at various loci around the clockface acetabulum demonstrated better correlation with morphological version ($R = 0.68$ for differences between 165° and 15°; $R = 0.57$ for differences between 135° and 45°) than with functional version ($R = 0.61$ for differences between 165° and 15°; $R = 0.50$ for differences between 135° and 45°). The better correlation with morphological version is unsurprising, as it minimizes the effect of pelvic tilt. The lack of a stronger correlation between morphological version and the differences in subtended angles along the various loci is also expected, as acetabular version was determined by the ARP, which takes into account a large number of points along the rim and projects them onto a plane, whereas the difference in subtended angles was determined along 2 points at the same level of femoral head coverage (eg, 45° vs 135°). Many authors have illustrated the high variability in coverage provided along each possible point around the acetabular clockface.[7,24,32] To create reproducible and reliable landmarks, 30° increments were used, in line with previous publications.[8,14] Further work is necessary to determine whether the degree of femoral head coverage is related to pelvic morphology.

There are several limitations to the current study. First, all assessments were made from axial imaging and not radiographs, thus missing a number of commonly used radiographic assessments. However, as a significant number of patients studied did not have any hip pathology, no anteroposterior pelvic radiograph was available for us to study without the associated, unnecessary radiation exposure. Second, all assessments performed were from CT scans and were thus in the supine position and not in the standing position, which would have provided additional information on what takes place in a loading position to the hip. Posture, as well as changes in position, can also affect the acetabular orientation.[23,34,43] Studies have demonstrated differences in pelvic and acetabular orientation between supine and standing radiographs.[34,43] When transitioning from supine to standing, there is an increase in pelvic tilt angle.[27,34,44] However, the supine position is a common, standardized, position in obtaining radiographs to assess the young adult hip.[7] What was more important for this anatomic study was to determine the interaction of the acetabular and spinopelvic morphology, and CT imaging in the supine position provided the necessary information. Third, no patient-reported outcome measures were used to properly define the control group; rather, a single orthopaedic hip surgery fellow, who was involved in determining whether any abnormal hip pathology existed on CT scan, evaluated all patient charts to ensure there had been no previous referral for a primary hip complaint. Thus, it is possible that some of the patients may have had hip symptoms. However, the primary reason for expanding the cohort to patients without known hip pathology was to increase the power of the study and to include patients from the whole spectrum of morphology.

CONCLUSION

This study illustrates the weak association between spinopelvic morphology and the morphological acetabular anteversion, which is relative to the anterior pelvic plane. Morphological anteversion (18.2 ± 9.0) was greater than physiological anteversion (14.7 ± 9.6). Morphological anteversion was determined primarily by the relative depth of the anterior and posterior acetabular rims. However, the physiological anteversion, which is the version relative to the horizontal and is how the acetabulum appears on radiographs, was associated primarily with the pelvic tilt angle. Thus, it is one's spinopelvic characteristics that determine the functional orientation of the acetabulum and are therefore important determinants of the joint's function. Future work should focus on whether spinopelvic morphology can be altered with focused, targeted physiotherapy to improve functional orientation and whether this would be sufficient to alleviate symptoms of impingement or dysplasia.

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