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No linear correlation between pelvic incidence and acetabular orientation

Retrospective observational study

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Abstract

Links between sagittal spinal alignment and acetabular orientation attract considerable research attention with the goal of understanding "hip-spine syndrome." However, whether pelvic incidence (PI) is related to acetabular orientation remains debatable. The purpose of the present study was to determine

1. whether the correlation between PI and acetabular orientation is present in pelvises of young healthy adults, and
2. whether the correlation is present in subgroups of sex, or between the left and right pelvis.

We analyzed 100 abdominopelvic computed tomography (CT) scans of skeletally healthy young adults. We measured PI and acetabular orientation with three-dimensional (3D) measurements. The orientation of 200 acetabula was measured using 3D reconstructed models of 100 pelvises in the coordinate system based on the anterior pelvic plane (APP). To quantify the acetabular orientation, the radiographic definitions of anteversion and inclination were used. To examine the correlation between acetabular orientation and PI, Pearson's correlation was used.

The mean PI was 46.9°±10.2°, and the mean acetabular orientation 15.3°±5.7° anteverted and 37.5°±3.9° inclined. While no significant difference in the PI was observed, the average acetabular orientation of female pelvises (anteversion, 17.5°±5.6°; inclination, 36.7°±3.7°) was more anteverted and less inclined compared to that of male pelvises (anteversion, 13.2°±4.9°; inclination, 38.3°±3.9°, respectively; *P* values < .05). The correlation between PI and acetabular orientation was statistically not significant. After division of study group by sex, the linear correlation between PI and acetabular orientation was not statistically supported. The asymmetry of the acetabular orientation between the left and right sides was not significant.

The linear relationship between anatomical acetabular orientation and PI was not evident in the normal population. Our finding thus proves the absence of a linear relationship between the upper and lower articular orientation of the pelvic segment and deepens the understanding of the characteristics of acetabular orientation and PI.

Abbreviations: 3D = three-dimensional, APP = anterior pelvic plane, ASIS = anterior superior iliac spines, CT = computed tomography, ICC = intra-class correlation coefficient, PI = pelvic incidence.

Keywords: anatomical acetabular orientation, pelvic incidence

1. Introduction

The term "hip-spine syndrome" describes a coexistence disorder of the hip and lumbar spine.[1] A previous study reported that 4.5% of patients who undergo total hip replacement have undergone lumbar surgery in the 5 years following hip surgery.[2] Patients with hip-spine syndrome are known to have worse outcome after treatment and higher complication rates than those who do not.[3–5] Salib et al reported that an increased risk of total

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hip dislocation after spinal fusion (5.2% postoperatively 1 year after spinal fusion vs 1.7% in controls).[3]

The pelvis connects the spine and hips and simultaneously acts as a versatile unit both in the spinal segment and in the hip joints.[6–8] As the changes in alignment of joints affect the load to bear in functional activities, changes in the orientation of the hip or spine caused by stiffness of either joint have been suggested to negatively affect the outcome. Thus, the orientation of the 2 has been raised as an important determinant of clinical results.[9,10]

The pelvic incidence (PI), which is a morphological parameter of the pelvis, characterizes positional alignment of the spine.[11,12] To emphasize this idea, Dubousset even referred to the pelvis as the "pelvic vertebra."[13,14] The acetabular orientation is a determinant of both native joint pathology and complications of the artificial joints.[15–18] The acetabular orientation is often described in 2 different coordinate systems. As the functional acetabular coordinate system is described in that of the whole body, the functional acetabular orientation in the native joint or the acetabular cup in the replaced joint is inherently influenced by the pelvic orientation.[19–22] In contrast, for the same reason, the acetabular orientation within the local pelvic coordinate system is not affected by the orientation of the pelvis.[19,20,23–25]

Based on the relationship between acetabular orientation in 2 different coordinate systems, the significance of correlation between PI and functional acetabular orientation can be further understood by evaluating the correlation between PI and pelvic orientation or between PI and anatomical acetabular orientation. Although there have been attempts to verify the links between PI and anatomical acetabular orientation, the results indicated divergent conclusions.[23,26–29] Prior studies on this had methodological limitations in measuring acetabular orientation, such as

1. measurements in 2 dimension, which is less reliable or
2. direct measurement from computed tomography (CT) sections, which is aligned to neither functional nor anatomical reference coordinate systems.

With the increased interest in the interplay between the spine and hips, understanding the relationship between the key parameters of these adjacent skeletal segments would improve our ability to recover the optimal alignments.[30–36]

The aims of the present study were to determine

1. whether the correlation between PI and acetabular orientation is present in pelvises of young healthy adults, and
2. whether the correlation is present in subgroups of sex or between the left and right pelvis.

We hypothesized that the orientation of the upper and lower joint surfaces of the pelvic segment, which is a link between the lumbar spine and the femurs, are correlated. To overcome the limitations of previous studies, the pelvis was reconstructed in three dimensions (3D) and pelvic parameters were measured consistently using innovative 3D measurements and in the local reference system. Thus, we measured the PI and acetabular orientation in the 3D model created using CT, evaluated the reliability of those, and examined the correlation between PI and acetabular orientation. (Fig. 1)

2. Method

2.1. Materials

This was a retrospective observational study. After institutional review board approval (AJIRB-MED-MDB-20-208), abdominopelvic CT scans obtained from May 2016 to February 2020 for

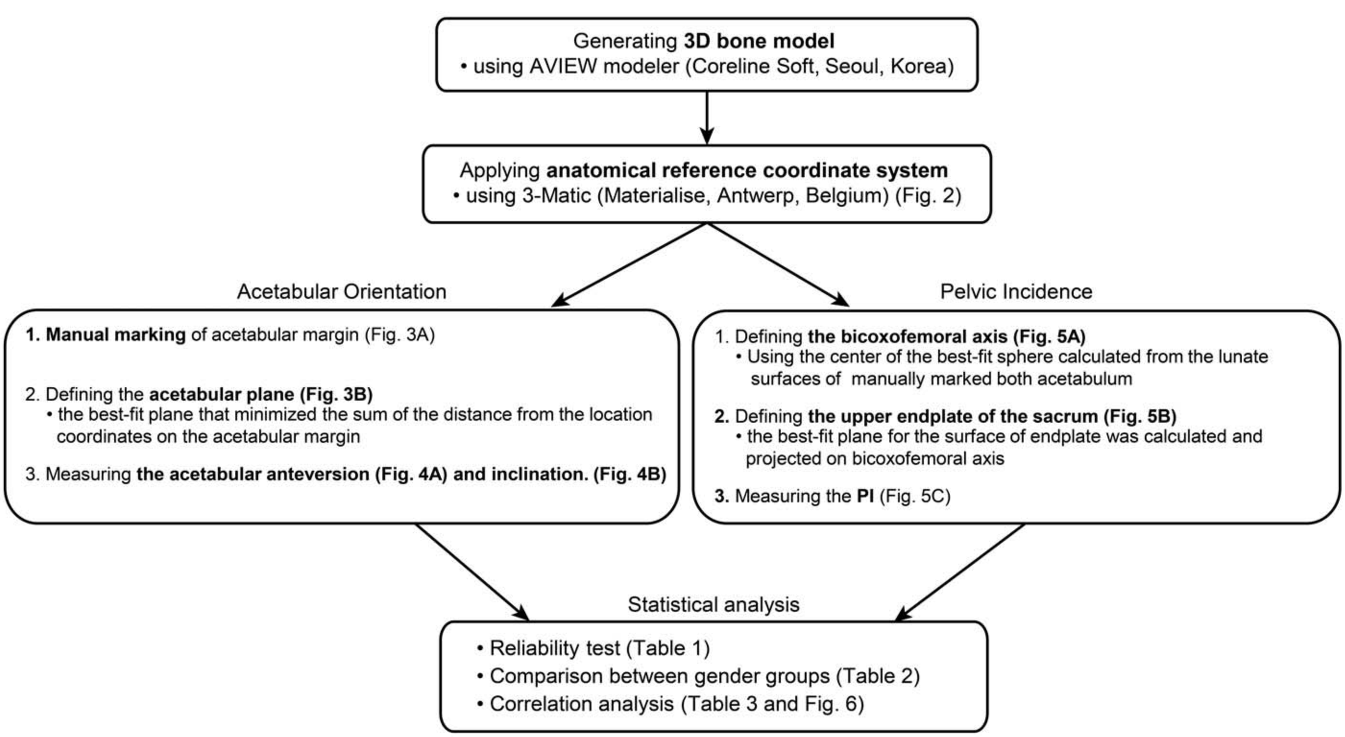

Figure 1. The flow chart of the study methodology.

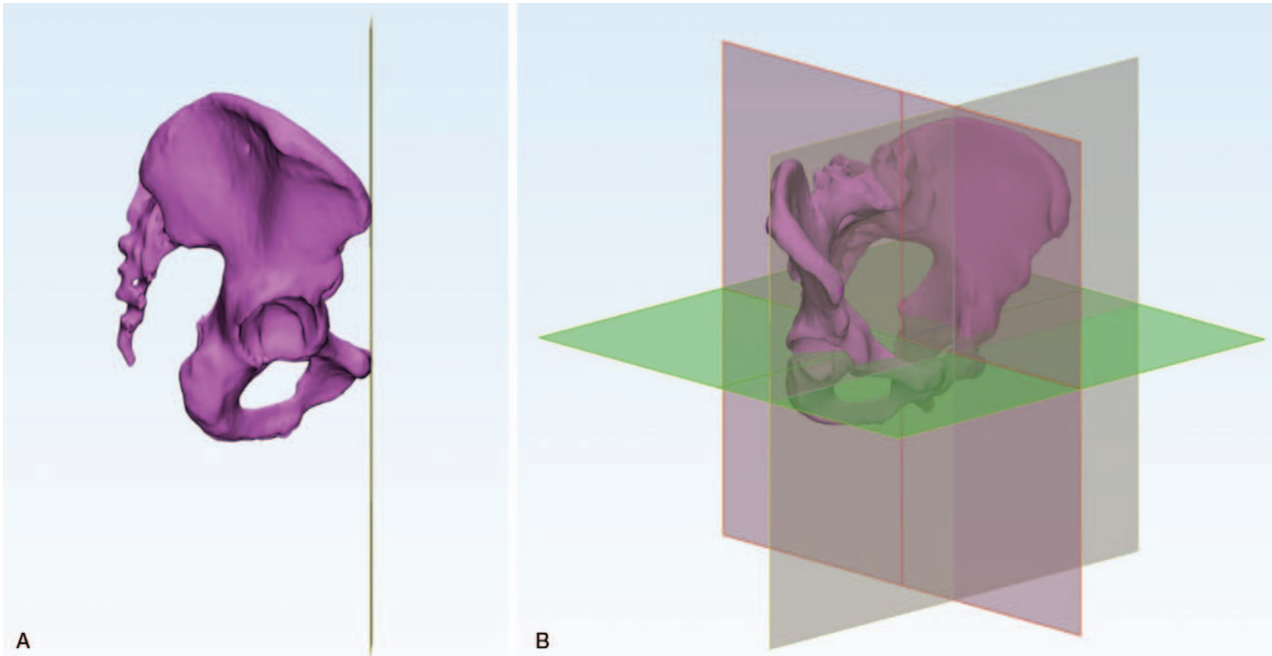

Figure 2. The anatomical reference coordinate system is established with the use of the anterior pelvic plane (APP). (A) The APP comprising both the anterior superior iliac spines (ASIS) and both pubic tubercles are defined as the coronal plane. (B) The plane orthogonal to the anterior pelvic plane and parallel to the bicoxofemoral axis was defined as the axial plane. The sagittal plane was defined as a plane orthogonal to the coronal and axial planes.

nontraumatic causes, such as gastroenteric and genitourinary organ pathology, were screened using the institution's picture archiving and communication system. We only included those patients aged between 25 to 39 years.[37] All through the review of clinical records, the patients with conditions that could influence bone improvement, including past pelvic injury, natural bone infection, known postponed or progressed sexual development, and other ailments or treatment (including endocrinopathy, neuromuscular illness, malignancy, or incendiary ailment) were excluded. After these exclusions, we identified 100 CT scans of 50 male and 50 female skeletally healthy young adults.

2.2. Measurement

3D measurement incorporated the following 5 stages:

1. segmentation of 3D bone models,
2. defining the reference coordinate system,
3. measurement of acetabular orientation, and
4. measurement of PI.

2.2.1. Segmentation and reconstruction of 3D bone models. The Digital Imaging and Communications in Medicine files of CT scans were imported to AVIEW modeler (Coreline Soft, Seoul, Korea) to reconstruct the 3D bone models.

2.2.2. Defining the reference coordinate system. The 3D pelvic model was imported to 3-Matic (Materialise, Antwerp, Belgium) for measurements. All the measurements were based on the anatomical reference coordinate system that was built based on the anterior pelvic plane (APP).[15,35,38] The APP comprising both anterior superior iliac spines (ASIS) and both pubic tubercles were defined as the coronal plane. The sagittal plane was normal to the vector passing through the bilateral ASISs. The plane perpendicular to both the coronal and sagittal planes defines the axial plane. The intersection axis between the axial and coronal planes was defined as the transverse axis (Fig. 2).

2.2.3. Measurement of acetabular orientation. The location coordinate values on the acetabular margin were manually marked. The acetabular plane was defined as the best-fit plane that minimized the sum of the distance from the location coordinates on the acetabular margin. The axis normal to the acetabular plane was defined as the acetabular orientation (Fig. 3). The radiographic definition was used to convert 3D orientation of the axis to numerical values (Fig. 4).[21] The angle between the acetabular axis and APP was measured as the radiographic acetabular anteversion. The angle between the projection of the acetabular axis onto the coronal plane and the transverse axis was measured as the radiographic acetabular inclination.

2.2.4. Measurement of PI. We assumed the acetabulum to be a part of the sphere, and the best-fit sphere was calculated to measure PI in the 3D pelvic model in the following manner. The lunate surface of the left acetabulum was marked, excluding the cotyloid fossa and acetabular notch. The best-fit sphere was then calculated, based on the marked area of the acetabular lunate surface. After unmarking the marked surface triangles, the same process was performed on the right side. The centers of both spheres were connected and defined as the bicoxofemoral axis.

The upper endplate of the sacrum was marked to output the center of gravity and the best-fit plane for the surface of the endplate. The center of gravity and normal axis of the best-fit plane were projected onto the midplane of bicoxofemoral axis and defined as point S and vector S.

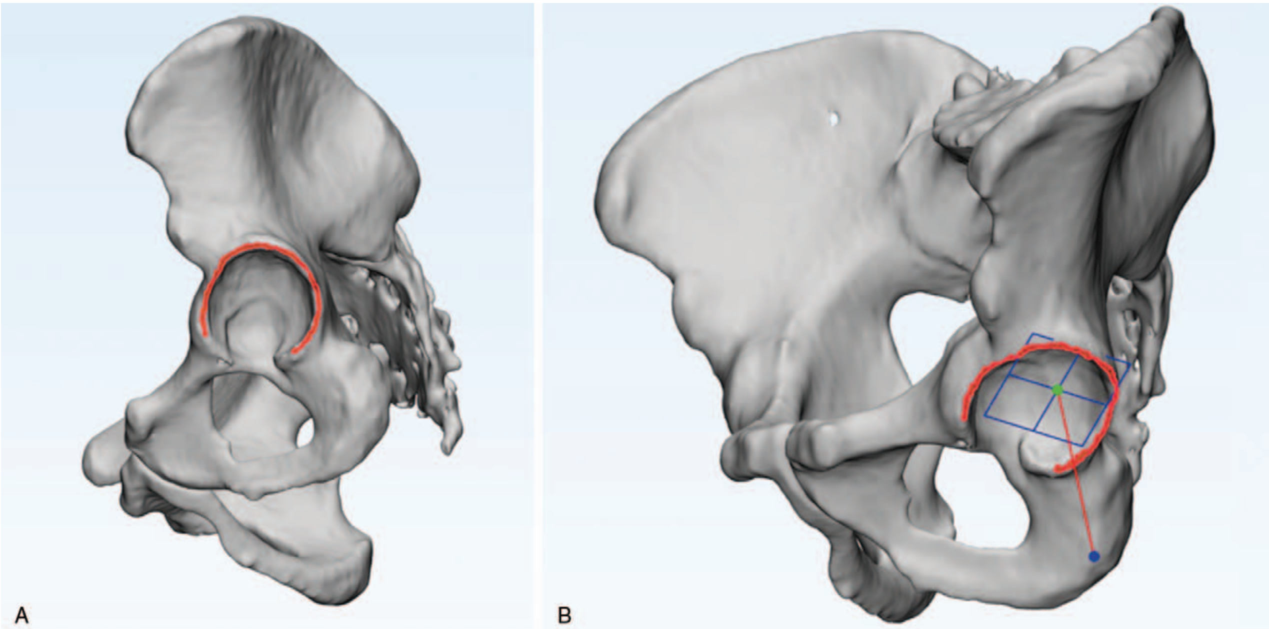

Figure 3. The representative axis for the acetabular orientation is defined based on the bony contour of acetabular rim. (A) The location coordinate values on the acetabular margin are manually marked. (B) The best-fit plane for the location coordinates is defined as the acetabular plane. The normal axis to the acetabular plane represents the acetabular orientation.

The angle between the line connecting the midpoint of the centers of the acetabular surfaces on both sides of the point S and vector S was measured as the 3D PI (Fig. 5).

All the measurements were performed by a fellowship-trained hip surgeon who had 8 years of experience as a board-certified orthopedic surgeon. Twenty pelvises were randomly selected from the total group for reliability assessment for 3D measurements of acetabular anteversion and PI. For inter-rater reliability, a fellowship-trained musculoskeletal radiologist, who had 3 years of experience as a board-certified radiologist, was employed. The

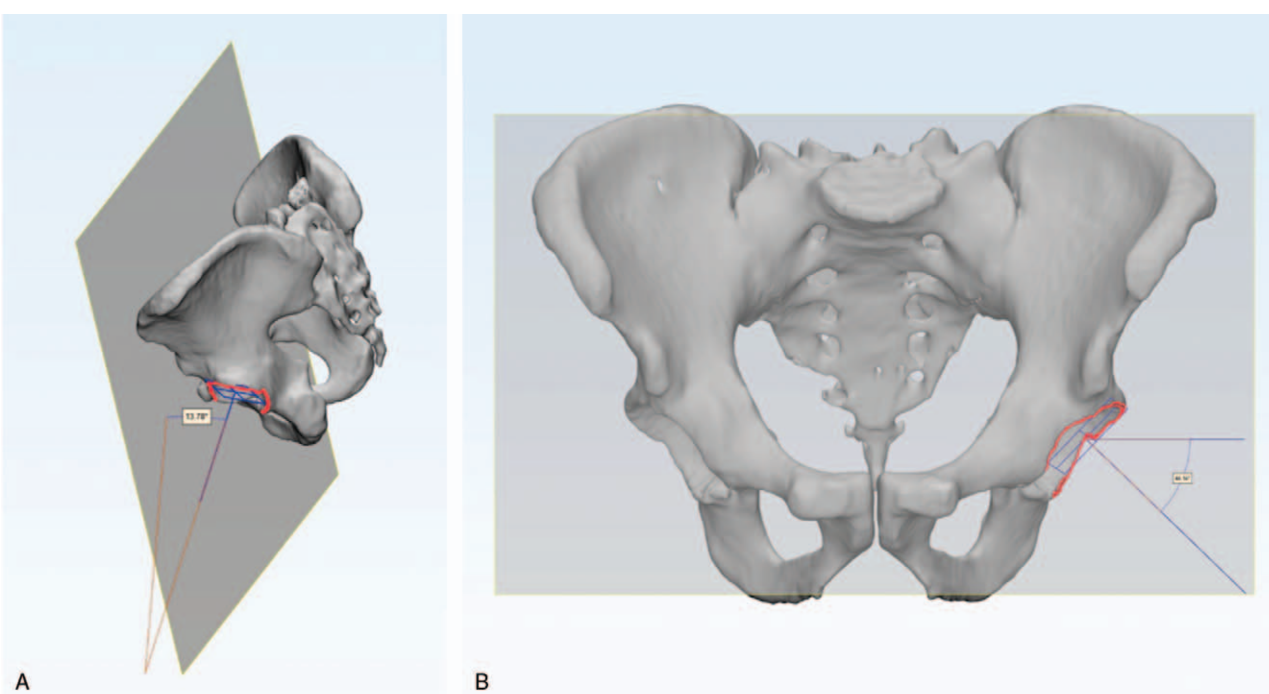

Figure 4. The acetabular orientation is measured in radiographic definitions. (A) The radiographic anteversion is the angle between the acetabular orientation and the APP. (B) The radiographic inclination is the angle between the bicoxofemoral axis and the projection of the acetabular orientation into the APP.

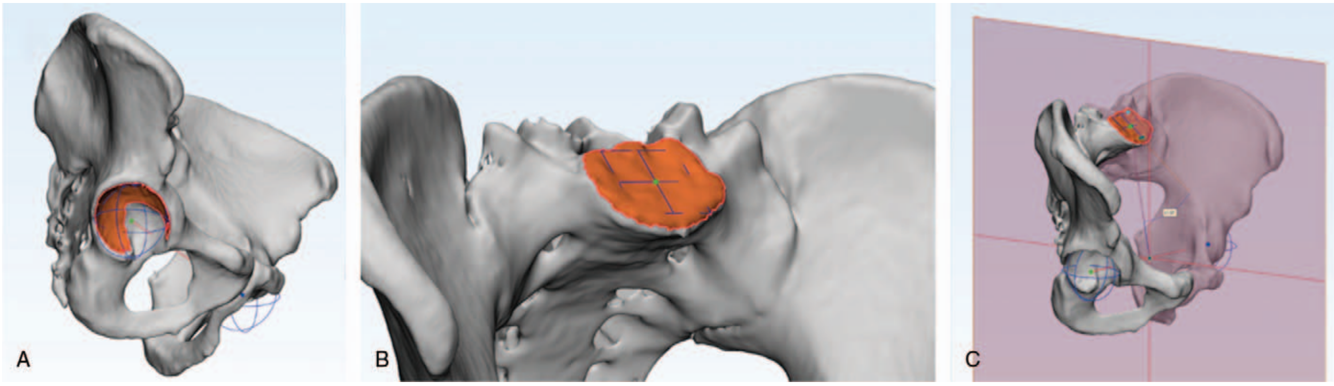

Figure 5. The pelvic incidence (PI) was measured three-dimensionally. (A) The lunate surface of the acetabulum is marked, excluding the cotyloid fossa and acetabular notch. (B) The location coordinate values on the upper endplate of the sacrum are manually marked to determine the midpoint and orientation of the S1 upper endplate. (C) PI is the angle between the orientation of the S1 upper endplate and the line connecting the midpoint of both acetabular centers and the midpoint of the S1 upper endplate.

former rater repeated the measurements after an interval of at least 2 months.

2.3. Statistical methods

Statistical analysis was performed by an independent statistician using the Statistical Package for Social Sciences software (SPSS version 22, IBM Corp., Armonk, NY).

The acetabular orientation and PI were presented using descriptive statistics. The intra-class correlation coefficient (ICC) [27] was used to evaluate the reliability of the method. Reliability was regarded as poor for less than 0.24, low for 0.25 to 0.49, moderate for 0.5 to 0.69, good for 0.70 to 0.89, and excellent for greater than 0.9.[39]

For the comparison between male vs female acetabular orientation and PI, an independent *t* test was used. For the comparison of left vs right acetabular orientation, a paired *t* test was used. To examine the correlation between acetabular orientation and PI, Pearson correlation was used. For the subgroup analysis, the correlation was applied to the male and female subgroups. $P < .05$ was considered to indicate statistical significance.

3. Results

The ICC of all the measurements was excellent (Table 1).

The mean age of both groups did not differ significantly between the males and females while body mass index of male subjects was higher than that of female subjects (Table 2). The acetabular orientation was 15.3°±5.7° anteverted and 37.5 ± 3.9° inclined in the APP anatomical coordinate system. The acetabular orientation of the male pelvis was less anteverted (anteversion, 13.2°±4.9°) and more inclined (inclination, 38.3°± 3.9°) compared to that of the female pelvis (anteversion, 17.5°± 5.6°; inclination, 36.7°±3.7°, respectively).

No significant difference was observed between left and right acetabular orientation, although the maximal difference was 5.0° in anteversion and 7.5° in inclination.

The correlation between PI and acetabular orientation was statistically not significant (Table 3 and Fig. 6). No significant correlation between PI and acetabular orientation was found after separation of male pelvises from female pelvises and left side from right side.

Table 1

Intraclass correlation coefficient (ICC) for 3D measurements of pelvic morphological parameters.

	Acetabular anteversion	Pelvic incidence
Intra-rater ICC	0.968 (0.940–0.983)	0.984 (0.961–0.994)
Inter-rater ICC	0.948 (0.901–0.972)	0.974 (0.934–0.990)

4. Discussion and conclusion

While no significant difference in PI was observed between the sexes, the difference in acetabular orientation between sexes was significant. The asymmetry of the acetabular orientation between the left and right sides was not significant. The hypothesis of the correlation between the morphological pelvic parameters of acetabular orientation and PI was not supported by our data from 100 skeletally mature and healthy pelvises, even after division into male and female patients.

PI has been reported to be an important morphological parameter that affects positional parameters of the spine and hip and regulates the sagittal balance and clinical symptoms such as

Table 2

Demographic data, acetabular orientational parameters, and pelvic incidence.

	Overall	Male	Female	*P* value
Number of pelvis		100	50	50
Age	35.2±4.2	35.2±4.3	35.3±4.1	.905
Body Mass Index	23.8±3.6	25.0±3.7	22.7±3.2	.002
Acetabular anteversion				
Left	15.6±5.9	13.3±4.9	17.9±6.0	<.001
Right	15.1±5.5	13.1±4.9	17.1±5.3	<.001
Overall	15.3±5.7	13.2±4.9	17.5±5.6	<.001
Acetabular inclination				
Left	38.0±3.9	38.8±3.9	37.2±3.7	.042
Right	37.0±3.8	37.8±3.9	36.1±3.5	.033
Overall	37.5±3.9	38.3±3.9	36.7±3.7	.003
Pelvic incidence	47.3±10.3	44.2±9.3	49.6±10.5	.008

Table 3

Correlation coefficient between pelvic incidence and acetabular orientation.

	Pelvic incidence		
	Overall	Male	Female
Acetabular anteversion			
Left	0.155 (0.125)	0.000 (1.000)	0.102 (0.482)
Right	0.159 (0.114)	0.038 (0.791)	0.090 (0.534)
Overall	0.160 (0.113)	0.020 (0.893)	0.098 (0.496)
Acetabular inclination			
Left	−0.044 (0.667)	−0.208 (0.147)	0.214 (0.135)
Right	−0.069 (0.497)	−0.083 (0.567)	0.056 (0.700)
Overall	−0.059 (0.557)	−0.152 (0.291)	0.148 (0.306)

*The values are the correlation coefficient r, and those in parentheses are *P* values.

lower back pain.[38,40–43] The acetabular orientation is considered as a key morphological feature that determines the functions and symptoms related to the acetabulum.[44,45] PI and acetabular orientation represent the anatomical orientation of the upper and lower joint surface of the pelvic segment, respectively.

Acetabular orientation is often used without clear definition in literature. As the definition of acetabular orientation established by Murray is based on the functional reference coordinate system, it has intra-subject variability and varies with the pelvic orientation.[21] Although Murray definition of acetabular orientation explained the difference in numerical expression according to the rotation sequence of Cardan angles to hip surgeons, the definition had limitations in being regarded as one of the pelvic morphological parameters because the reference coordinate system is based on the landmarks of the pelvis. Thus, the definition of acetabular orientation by Murray is called "functional acetabular orientation."[38,46] With the convention of Lewinek, APP is a widely used frame for the pelvic coordinate system for the description of acetabular orientation.[24,47,48] With the landmarks for the coordinate system restricted within the pelvis, such as the ASISs and pubic tubercles, the acetabular orientation can be standardized as a morphological factor. The same methods for defining acetabular orientation in the APP coordinate system were used in various terms to depict the morphological acetabular orientation within the pelvic reference frame.[46] Defining the acetabular orientation on the APP coordinate system established by specific anatomical landmarks is collectively referred to as the "anatomical acetabular orientation."

The hypothesized link between the orientation of the upper and lower joint surfaces of the pelvic segment has attracted researchers. The analysis of the hypothetical correlation between pelvic parameters of acetabular orientation and PI was preliminarily attempted by Boulay et al.[23] They measured 3D spatial orientation of the acetabulum in 12 cadaveric pelvises using an electromagnetic device. Although they constructed a coordinate system different from the APP coordinate system, as the reference landmarks were within the pelvis, their coordinate system is intrinsically similar to the APP coordinate system, as acetabular orientation stays the same irrespective of the orientation of pelvis. In contrast to our results, they found a significant correlation between PI and acetabular orientation and significant asymmetry of the right and left acetabular. This finding may be due to the small sample size. Legaye et al. investigated the correlation between PI and acetabular orientation using 51 human pelvises. In this study, no correlation between the 2 was reported, which is in line with our results.[26] Another study that systematically distinguished the functional and anatomical acetabular orientation was performed with the EOS system, which is a full-body, biplanar stereo-radiography with 3D reconstruction, and reported that PI determines the inclination of the APP in the standing position, which in turn

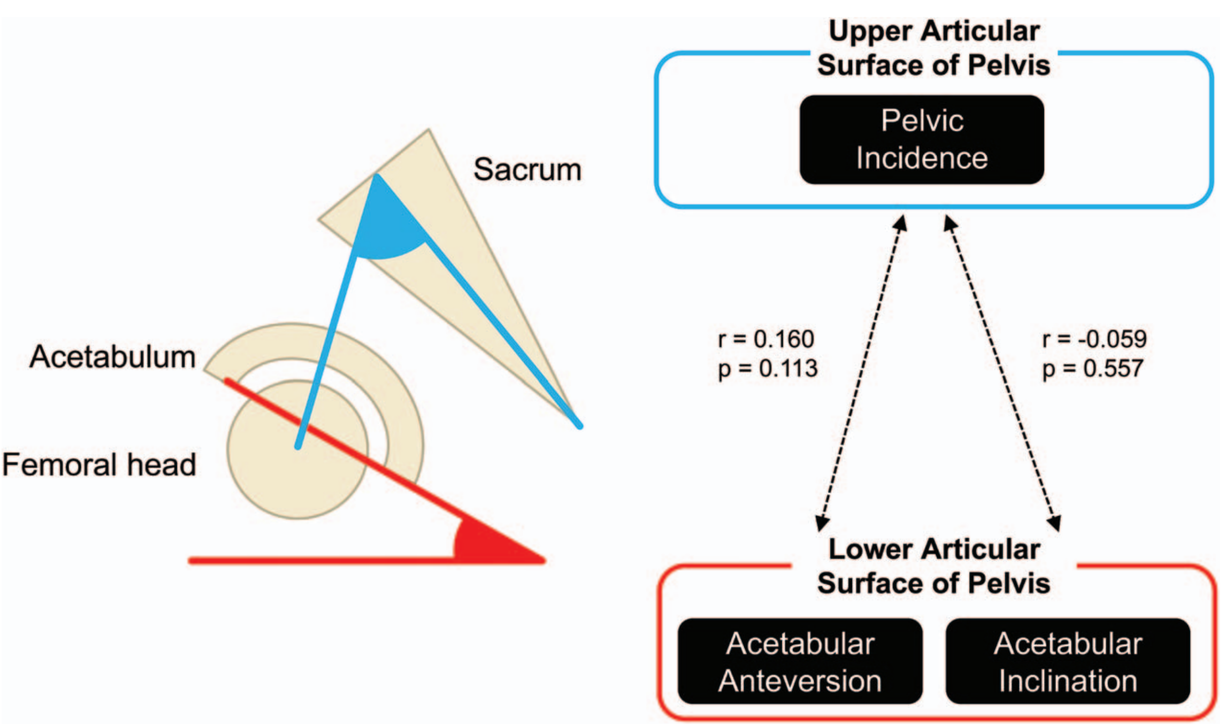

Figure 6. Graphical summary of results regarding relationship between the acetabular inclination, anteversion, and PI.

defines the functional orientation of acetabular.[46] According to their data, the orientation of the standing APP plane was affected by PI. The difference of acetabular orientation in APP and the functional coordinate system was correlated with PI. Combining our results of nonrelevance between both morphological parameters of APP acetabular orientation and of PI, we could infer the features of sagittal balance such as that PI has correlation with standing APP orientation, which in turn has a greater role in explaining that the functional acetabular orientation, rather than PI, has direct correlation with anatomical acetabular orientation.

The pelvis is one of the skeletal structures with the most differences between the sexes. According to the results of subgroup analysis (male vs female), the degree of difference was not identical in the upper and lower joint surfaces of the pelvic segment. Although the difference of PI was not significant, the acetabular orientation was significantly different based on sex, and it was consistent with the results of previous studies.[49–52] Considering both

1. the sex-based difference of the orientation of both the upper and lower articular surface of the pelvic segment and
2. the difference in BMI based on sex in our study population, the linear relationship was tested again after dividing the study population into subgroups of males and females.

Even after the subgroup analysis, the hypothesis of linear correlation between PI and acetabular orientation was not statistically supported.

There is an increased prevalence of patients with concomitant degeneration of the hip and lumbosacral spine in the aging population.[2,4,53,54] Recent studies have focused on total hip arthroplasty instability in patients with both lumbar spine and hip pathologies.[3,5,55] Two pathomechanisms regarding how malalignment of spine increases the risk of dislocation after hip arthroplasty have been proposed. First, spinal pathology or fusion prevents the pelvis from tilting enough to clear the anterior lip of the acetabular cup while changing from the standing position to the sitting position.[3,10,55] Second, the abnormal position of the pelvis (abnormal pelvic tilt) causes malposition of the acetabular cup in total hip arthroplasty, even if the components are correctly positioned according to Lewinnek proposed “safe zone.”[53]

The finding of the present study denies the simple rule to use the orientation of upper articular surface for reconstruction of the lower articular surface of acetabular orientation. For the long bones the of human body, simple rules for correction of articular surface guide surgeons to achieve a satisfactory alignment.[56]

With the marked divergence in the pelvic morphology and the significant influence of spinal alignment on the pelvic orientation in the standing position, the results of the present study provide the possible explanation that the root of the relevance between the upper articular surface orientation, which is represented as PI, and the difference between anatomical and functional acetabular orientation may barely originate from the morphological correlation between the upper and lower articular surface orientation.[46] This observation will help deepen the understanding of the characteristics of acetabular orientation and PI.

The study had some limitations. The study subjects were enrolled according to time interval without clinical interviews. However, we limited the age of subjects and the purpose of CT scanning into those without hard tissue abnormalities. The review of medical records helped exclude patients with conditions that could affect bone development. The consistency of acetabular orientation and pelvis incidence between study subjects with the historical data supports that the study subjects in the present study did not differ much from the historical data in terms of general characteristics.[25,49] The 3D methods of measurement with CT scans are limited by the resolution of the images. Further, surface modifications such as smoothing and surface simplification through mesh size reduction could lead to loss of accuracy. There was a difference in the BMI between men and women. To overcome such differences in the BMI, we also performed a subgroup analysis further divided by sex. Based on the previous research which reported that BMI was not correlated with PI and AA, the difference in BMI based on sex was not regarded as a confounder. [57,58]

PI showed no statistically significant difference between both sexes, while acetabular orientation showed statistically significant difference the 2 groups. No significant right and left difference in acetabular orientation was observed as well. The correlation between morphological pelvic parameters known as PI and acetabular orientation was not supported by our study and the subgroup analysis of both sexes revealed the same result. The nonrelevance of articular orientation between the upper and lower pelvis would aid surgeons in understanding the anatomical characteristics of the pelvis.

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