CLINICAL ARTICLE

Does Spinal Alignment Influence Acetabular Orientation: a Study of Spinopelvic Variables and Sagittal Acetabular Version

Kristen E Radcliff, MD, Christopher K Kepler, MD, MBA, Michael Hellman, MD, Camilo Restrepo, MD, Kwang Am Jung, MD, Alexander R Vaccaro, MD, PhD, Todd J Albert, MD, Javad Parvizi, MD

Department of Orthopaedic Surgery, Rothman Institute, Thomas Jefferson University Hospital, Philadelphia, Pennsylvania, USA

Objective: Although hip alignment and spinal alignment have been studied individually, there is little information concerning the relationship between them. The questions addressed in this study are: (i) Is there a reproducible measure of sagittal plane acetabular orientation; (ii) Is sagittal plane acetabular orientation determined more by pelvic incidence (PI) or acetabular wall coverage?

Methods: Data on patients who had undergone screening by CT scan of the pelvis for non-orthopedic indications from 2005–2010 were retrospectively studied. There were 164 patients of mean age 59 years (range, 27–87). Patients with pelvic trauma, hip arthroplasty or other hip pathology were excluded. Measurements of relevant acetabular and spinopelvic variables were made in the sagittal plane. The sacro-acetabular angle (SA) was defined as the angle between a tangent line to the anterior and posterior walls of the acetabulum and the S₁ endplate. Multiple regression analysis was used to determine which factors contribute to SA angle.

Results: The mean sacro-acetabular angle was 72° (SD = 14.8°). Center edge angles (CEAs) were measured at the anterior and posterior walls of the acetabulum. Mean anterior CEA was 69° (SD = 8.3°) and posterior CEA 107° (SD = 16.4°). Regression analysis revealed the largest significant predictors of SA angle were PI and A-CEA.

Conclusions: Sagittal acetabular orientation is related to spino-pelvic balance and morphological characteristics. Increased PI or posterior wall coverage corresponds to a more vertical acetabular orientation. Sagittal plane acetabular alignment may be an important variable in achieving favorable results after reconstruction.

Key words: Acetabular version; Hip-spine syndrome; Pelvic incidence; Spino-pelvic alignment

Introduction

Back pain and other related lumbar spine complaints may occur following total hip arthroplasty¹. Degenerative disease of the lumbar spine may be a contributing factor to this phenomenon, which is called “hip spine syndrome”². Although spinal conditions are known to exacerbate hip disease and vice versa, no known angular relationships between spinal alignment and hip alignment have been shown to explain a causal relationship.

Sagittal plane measures, including the relationship of the spine to the pelvis, have been shown to be critical variables in spinal reconstruction^{3–6}. Spinal alignment should facilitate upright posture such that minimal exertion and work by muscles are required⁷. Spinal alignment is related to lumbar lordosis and various pelvic variables^{8,9}. Lumbar lordosis is related to pelvic incidence (PI) because the lumbar spine has to “overcome” the overall vertical orientation of the S₁ endplate in order to achieve upright posture. PI is an important variable

Address for correspondence Kristen E Radcliff, MD, Department of Orthopaedic Surgery, Rothman Institute, Thomas Jefferson University, Philadelphia, USA 19107 Tel: 001-609-5733301; Fax: 001-215-9554322; Email: radcliffk@gmail.com; sidhug1986@gmail.com

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that is related to outcomes of lumbar spine fusions for deformity, spondylolisthesis, spinal osteotomies and treatment of thoracolumbar burst fractures^{7,10–15}. Additionally, PI may be related to the incidence of isthmic spondylolisthesis because some individuals with high PI (more vertical S₁ orientation) are particularly prone to spondylolisthesis, possibly due to shear forces at the L₅-S₁ interface. Finally, other studies have established a direct relationship between PI and early hip osteoarthritis¹⁶.

The acetabulum has been extensively studied in the coronal and axial planes^{17–19}. Previous studies have established the acetabular orientation relative to the coronal and axial planes based on CT scan measurements²⁰. Variations in acetabular orientation and morphology in the coronal and sagittal planes have a profound effect on the pathogenesis of hip disease^{18,19}. Acetabular morphology has received increasing attention in recent published reports, acetabular retroversion, femoral-acetabular impingement due to overcoverage, and dysplasia having been implicated in degenerative conditions^{20–31}. However, to the authors' knowledge, there have been no studies on normal sagittal plane acetabular orientation. Standard anteroposterior pelvic radiographic measurement techniques attempt to eliminate the effect of sagittal alignment by rotating the X-ray beam in the sagittal plane¹⁷ to achieve a distance of less than 2.5 cm between the tip of the coccyx and the pubic symphysis³².

The purpose of this study was to create a reproducible measurement of the sagittal plane alignment of the acetabulum and determine whether PI or extent of wall coverage is the greater determinant of sagittal orientation. The specific questions addressed by this study were: (i) what is the normal sagittal orientation of the acetabulum; and (ii) is PI or extent of wall coverage a greater predictor of sagittal acetabular coverage?

Materials and Methods

Patient Variables

Consecutive patients who had screening CT scans with sagittal views for non-orthopaedic related problems at our institution, an urban Level I trauma center, between February 2005 and April 2010 were enrolled in this retrospective study. In all, 164 hips were included. The mean patient age was 59 years (range, 27–87) and there were 44 male and 120 female subjects. The CT scans had most commonly been obtained for evaluation of gastrointestinal (75 cases), urologic (44 cases) and vascular systems (11 cases).

Exclusion criteria were established to accomplish the study goal of obtaining spinopelvic and acetabular measurements from subjects without related abnormalities. The following radiological exclusion criteria were applied: dysplastic hips, definitive evidence of osteoarthritis as determined by the attending radiologist, evidence of previous hip surgery in one or both hips, or evidence of spine surgery. All CT scans were analyzed by a single observer in a 2D bone window using the measurement tools available in

Fig. 1 Diagram demonstrating sacral slope, pelvic tilt and pelvic incidence. PI, pelvic incidence; PT, pelvic tilt; SF, sacral-femoral; SS, sacral slope.

the Stentor PACS software system (Philips, Andover, MA, USA).

Each patient was characterized by a previously described spinopelvic variable³³. PI was defined according to the definition of Legaye *et al.* (Fig. 1)⁹ as the angle between the perpendicular to the sacral endplate at its midpoint and the line connecting this point to the idealized center of the femoral heads. Pelvic tilt was defined as the angle between a vertical line and a line connecting the idealized center of the femoral heads to the midpoint of the sacral endplate. Four new sagittal plane acetabular variables were defined: sacro-acetabular angle (SA), anterior center-edge angle, posterior center-edge angle, and total center-edge angle (Table 1).

Sacro-acetabular angle was defined as the angle between a tangent line to the anterior and posterior walls of the acetabulum and the S₁ endplate (Fig. 2). It is independent of position and measures the slope of the acetabulum relative to the S₁ endplate. Increased SA angle corresponds to a more vertical acetabular orientation.

TABLE 1 Angle relationships of spinopelvic variables

Measurement		Axial	Sagittal
PI	Point A	Posterior to sacral endplate	Midpoint of sacral endplate
	Point B	Sacral endplate	Midpoint of sacral endplate
	Point C	Midpoint between center of femoral heads	Center of femoral head
A-CEA	Point A	Sacral endplate	Midpoint of sacral endplate
	Point B	Center of femoral head	Center of femoral head
	Point C	Center of femoral head	Anterior edge of bony acetabulum
P-CEA	Point A	Sacral endplate	Midpoint of sacral endplate
	Point B	Center of femoral head	Center of femoral head
	Point C	Center of femoral head	Posterior edge of bony acetabulum
SA angle	Point A	Sacral endplate	Midpoint of sacral endplate
	Point B	Center of femoral head	Center of the femoral head
	Point C	Center of femoral head	Tangent between the anterior and posterior edges of bony acetabulum

A, anterior; CEA, center-edge angle; P, posterior; PI, pelvic incidence; SA, sacro-acetabular.

Morphological measurements were also constructed in reference to a reference line from the midpoint of the sacral endplate and the idealized center of the femoral heads, referred to from herein as the sacral-femoral (SF) line. Further, all measurements on the acetabulum were performed in the sagittal plane at the center of the femoral head in reference to the coronal plane.

Center-edge angles were measured in reference to the SF line to determine the extent of acetabular wall coverage in the sagittal plane. Anterior center-edge angle measures the anterior coverage of the acetabulum in relation to the femoral head. It is defined as the angle between the SF line and a line connecting the center of the femoral head to the most distal extent of the anterior wall of the acetabulum (Fig. 3) in a sagittal plane bisecting the femoral head. Posterior center-edge angle is the angle between the SF line and the posterior wall of the acetabulum in a sagittal plane bisecting the femoral head. It is defined as the angle between the SF line and a line connecting the center of the femoral head to the posterior wall of the acetabulum (Fig. 4). Total center-edge angle measures the total coverage of the acetabulum and is defined as anterior center-edge angle + posterior center-edge angle. The relative percentage of total coverage defined by the anterior wall (anterior center-edge angle/total center-edge angle), posterior wall (posterior center-edge angle/total center-edge angle), and the ratio between anterior and posterior wall coverage (anterior center-edge angle/posterior-center edge angle) was also defined.

The mean, range and standard deviation of each measurement was calculated. In all patients, S₁ endplate morphology permitted measurement. All measurements were tested for variation according to age, sex, height, weight and body mass index (BMI). Pearson correlation coefficients were used to determine the relationships between the radiographic variable. A step-down multiple linear regression model was constructed to identify radiographic variables that predicted the

Fig. 2 Diagram demonstrating sacro-acetabular angle. SA, sacro-acetabular angle.

Fig. 3 Anterior center edge-angle is depicted. A, anterior; CEA, center-edge angle; SF, sacral-femoral.

sacro-acetabular angle. A random sample of the measurements was repeated by another blinded observer (KR). Pearson correlation between observers for all measurements was 0.93. Kappa values representing agreement between observers were calculated to describe measurement reliability and analyzed according to previously described criteria^{34,35}. Values of 0.81–1.00 indicate excellent concordance, 0.61–0.80 substantial concordance, 0.41–0.60 moderate concordance, 0.21–0.40 fair concordance, and 0.00–0.20 poor concordance. Interobserver reliability was checked by a second experienced observer repeating the measurements on the first twenty cases. Overall kappa interobserver reliability was 0.86 percent, denoting excellent concordance of SA angle measurement.

Results

The normal sagittal orientation of the acetabulum compared to the S_1 endplate, called the sacro-acetabular angle, was 72° (range 32° – 106° , two patients with measurement $<50^\circ$, $SD = 14.8^\circ$). Other sagittal pelvic and acetabular measurements were as follows: anterior center-edge angle 69° (range 43° – 90° , $SD = 8.3^\circ$), posterior center-edge angle 107° (range 60° – 147° ,

$SD = 16.4^\circ$), total center-edge angle 176° (range 122° – 220° , $SD = 18.7^\circ$), antero-posterior ratio 0.66 (range, 0.45–1.16, $SD = 0.13$), and PI 55° (range 26° – 80° , $SD = 9.6^\circ$). There was a weak inverse correlation between height and sacro-acetabular angle ($r = -0.231$, $P = 0.004$) and a weak direct correlation between age and PI ($r = 0.372$, $P < 0.001$). There were no further significant correlations between age, height, weight, BMI, and radiographic variables (Table 2). According to independent samples *t*-test, there were no significant ($P > 0.05$) differences in radiographic variables between male and female subjects.

To determine the relative contributions of PI and center-edge angles to sacro-acetabular angle, various correlations were assessed. Significant direct correlations were found between sacro-acetabular and PI ($r = 0.641$, $P < 0.001$), posterior center-edge angle ($r = 0.524$, $P < 0.001$), total center-edge angle ($r = 0.379$, $P < 0.001$). Therefore, a more horizontal sacral endplate (decreased PI) corresponds to a smaller sacro-acetabular angle and more horizontal acetabular orientation (Fig. 5). Similarly, a direct correlation was identified between sacro-acetabular angle and percent coverage of posterior wall ($r = 0.514$, $P < 0.001$), suggesting that increased posterior wall coverage results in a more vertical acetabular orientation (Fig. 6). An inverse correlation was found between

Fig. 4 Posterior center-edge angle is shown. CEA, center-edge angle; P, posterior; SF, sacral-femoral.

TABLE 2 Pearson correlation (*r*) matrix between measurements and subject characteristics

Measurement		SA angle	PI	A-CEA	P-CEA	T-CEA	Anterior-posterior CEA ratio	Anterior wall coverage	Posterior wall coverage	Hip Alpha angle
Age	<i>r</i>	0.12	0.37	0.12	-0.05	0.01	0.11	0.12	-0.12	0.09
	<i>P</i>	0.14	0.00	0.13	0.52	0.92	0.14	0.12	0.12	0.23
Height	<i>r</i>	-0.23	-0.09	0.06	-0.21	-0.16	0.23	0.22	-0.22	0.27
	<i>P</i>	0.00	0.24	0.47	0.01	0.05	0.00	0.01	0.01	0.00
Weight	<i>r</i>	-0.78	-0.15	-0.11	-0.04	-0.08	-0.01	-0.03	0.03	0.14
	<i>P</i>	0.34	0.06	0.19	0.65	0.34	0.86	0.75	0.75	0.08
BMI	<i>r</i>	0.12	-0.15	-0.21	0.04	-0.05	-0.15	-0.16	0.16	0.01
	<i>P</i>	0.89	0.06	0.01	0.61	0.51	0.06	0.05	0.05	0.90

Bold face indicates statistically significant values. A, anterior; BMI, body mass index; CEA, center-edge angle; P, posterior; PI, pelvic incidence; SA, sacro-acetabular.

sacro-acetabular angle and anterior center-edge angle ($r = -0.175$, $P = 0.025$) suggesting that decreased anterior wall coverage results in a more vertical acetabular orientation (Table 3). Finally, a multiple regression model demonstrated that the sacro-acetabular angle could be best constructed using two independent variables: PI (coefficient 1.08, $P < 0.001$) and anterior center-edge angle (coefficient -0.55 , $P < 0.001$) which resulted in $R^2 = 0.71$. No other variables approached significance and the final model had minimal collinearity.

Discussion

The present study has established a measurement technique for sagittal plane acetabular orientation with respect to the S₁ endplate as a fixed landmark and demonstrated that it is a function of both intrinsic acetabular morphology and spinopelvic variables. Normal acetabular sagittal orientation is 72° anterior superior, posterior inferior relative to the S₁ endplate. PI is a more important determinant of sacro-acetabular angle than extent of wall coverage.

Fig. 5 There is a direct correlation between pelvic incidence and sacro-acetabular angle. As pelvic incidence increases from A to B, the SA angle increases. PI, pelvic incidence; SA, sacro-acetabular angle.

Fig. 6 There is a direct correlation between wall coverage and sacro-acetabular angle. As posterior wall coverage increases from A to B, the SA angle increases. SA, sacro-acetabular angle.

Limitations of this study include its retrospective nature, lack of clinical information including that concerning the presence of clinically significant hip osteoarthritis or symptomatic hip impingement, and lack of standing spinal alignment radio-

graphs. Patients were excluded based on imaging study reports of hip osteoarthritis but without clinical assessment (e.g. Harris Hip Score). To account for the effect of supine positioning, angular measurements were created and defined relative to

TABLE 3 Pearson correlation coefficients (*r*) matrix between measurements

		PI	A-CEA	P-CEA	T-CEA	Anterior-posterior CEA ratio	Anterior wall coverage	Posterior wall coverage	Hip Alpha angle
SA angle	<i>r</i>	0.64	-0.18	0.52	0.38	-0.50	-0.51	0.51	-0.09
	<i>P</i>	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.27
PI	<i>r</i>	—	0.19	0.13	0.20	0.04	0.03	-0.03	0.00
	<i>P</i>	—	0.02	0.10	0.01	0.63	0.69	0.69	0.98
A-CEA	<i>r</i>	—	—	0.06	0.49	0.53	0.56	-0.56	-0.06
	<i>P</i>	—	—	0.44	0.00	0.00	0.00	0.00	0.41
P-CEA	<i>r</i>	—	—	—	0.90	-0.79	-0.78	0.78	-0.12
	<i>P</i>	—	—	—	0.00	0.00	0.00	0.00	0.13
T-CEA	<i>r</i>	—	—	—	—	-0.46	-0.44	0.44	-0.13
	<i>P</i>	—	—	—	—	0.00	0.00	0.00	0.09
Anterior-posterior ratio	<i>r</i>	—	—	—	—	—	0.995	-0.995	0.06
	<i>P</i>	—	—	—	—	—	0.00	0.00	0.46
Anterior wall coverage	<i>r</i>	—	—	—	—	—	—	-1.00	0.06
	<i>P</i>	—	—	—	—	—	—	0.00	0.44
Posterior wall coverage	<i>r</i>	—	—	—	—	—	—	—	-0.06
	<i>P</i>	—	—	—	—	—	—	—	0.44

A, anterior; BMI, body mass index; CEA, center-edge angle; P, posterior; PI, pelvic incidence; SA, sacro-acetabular.

Fig. 7 Sacro-acetabular angle carries additional information about sagittal acetabular orientation that is not captured by pelvic incidence. As an example, patient A and B have the same PI but as the acetabulum assumes a more vertical orientation in patient B, the SA angle increases but the PI does not change. There is less superior acetabular coverage in patient B than in patient A. PI, pelvic incidence; SA, sacro-acetabular angle.

other fixed pelvic landmarks. Finally, the implications of sacro-acetabular angle are largely theoretical at this time. However, the purpose of this study was to establish a consistent measurement of sagittal plane acetabular orientation. Future studies should investigate the implications of sacro-acetabular angle on clinical practice. This technique is designed for CT scan or MRI because of radiographic overlay of the contralateral hips. It may be adapted to standing lateral radiographs in future studies. Future studies may also evaluate spinopelvic alignment in patients with hip osteoarthritis and/or after total hip arthroplasty. The subjects included in this analysis were assumed to represent a normative, but not normal, population sample. Because there is a high prevalence of spinal disease in the general population, it is unlikely that the subjects were entirely free of hip or spine disease. The exclusion criteria of radiological evidence of previous hip or previous spinal surgery were included to prevent introduction of bias caused by iatrogenic deformity. Assuming that patients with severe hip and spinal disease would have undergone surgical intervention, the study subject probably represents a normative population, that is, including subjects with mild to moderate degenerative joint disease or spinal osteoarthritis.

We created the sacro-acetabular angle to define the angular orientation between the acetabulum and the S_1 endplate, a fixed pelvic landmark. In contrast, the PI describes the relationship of the S_1 endplate to a fixed point at the idealized centers of the femoral heads. The PI is therefore a

translational measurement of anteroposterior position of the femoral heads to the S_1 endplate and is not sensitive to acetabular version. For instance, if the acetabulum were more vertical or more horizontal, PI would remain unchanged but the sacro-acetabular angle would change (Fig. 7). Both measurements assume no change in the orientation of the relatively immobile sacroiliac joints and are therefore considered to be intrinsic properties of the pelvis. However, the sacro-acetabular angle is sensitive to sagittal acetabular version, which the PI does not consider.

We determined that the sacro-acetabular angle is more a function of PI than of extent of wall coverage. The correlation and regression data indicate that, in this study, increasing PI (corresponding to a more vertical S_1 endplate orientation), results in greater sacro-acetabular angle (resulting in a more vertical acetabulum, Fig. 5). Additionally, increasing posterior acetabular wall coverage or decreasing anterior wall coverage effectively results in a more vertical acetabular orientation (Fig. 6). We theorize that maintenance of optimal acetabular coverage in the standing position is a key component of upright posture and secondarily affects spinal alignment. We postulate that pelvic tilt and alignment shifts in individuals through the hips to maximize femoral head coverage and surface area and reduce joint contact pressures. Individuals may compensate for increased PI and SA angle by increasing sacral slope to maintain horizontal acetabula. Individuals with abnormal sacro-acetabular alignment may be more susceptible

to abnormal pelvic tilt and sacral slope and therefore secondary degenerative processes at the lumbosacral junction. Specifically, individuals with large sacro-acetabular angles may be predisposed to posterior femoroacetabular impingement (Fig. 7) and may otherwise develop secondary low sacral slope to compensate. Future studies should include measurement of average sacro-acetabular angle to determine whether SA is predictive of sagittal plane alignment. Since multiple previous studies have demonstrated that lumbar lordosis is related to PI and sacral slope^{3,9,11,36}, we suspect that lumbar alignment may also correlate with sacro-acetabular angle. These findings are important because femoroacetabular impingement results from overcoverage or malorientation of the acetabulum in the axial plane. Therefore, when surgeons are considering acetabuloplasty versus redirectional osteotomies to optimize

acetabular version, sagittal plane acetabular orientation may be an important component of reconstruction²⁹. Conversely, changing acetabular version (through arthroplasty) may affect PI and, ultimately, lumbar alignment. The interrelationship of acetabular and spinal orientation may underlie the phenomenon described as “hip-spine syndrome” in which osteotomy or reconstruction of one component may result in symptomatic pathology of the other element.

In conclusion, this study establishes the sagittal plane angular orientation relative to a fixed, midline spinal landmark in normal individuals. We determined that PI is a larger determinant of sagittal acetabular profile than is extent of wall coverage. Future studies should evaluate the effect of this variable, the sagittal acetabular profile, on spinal and acetabular reconstruction.

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