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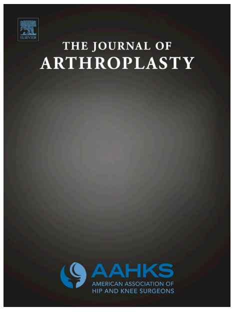

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Abstract:

Introduction: To create a safe zone, an understanding of the combined femoral and acetabular mating during hip motion is required. We investigated the position of the femoral head inside the acetabular liner during simulated hip motion. We hypothesized that cup and stem anteversion do not equally affect hip motion and combined hip anteversion.

Methods: Hip implant motion was simulated in standing, sitting, sit-to-stand, bending forward, squatting, and pivoting positions using the MATLAB software. A line passing through the center of the stem neck and the center of the prosthetic head exits at the polar axis (PA) of the prosthetic head. When the prosthetic head and liner are parallel, the PA faces the center of the liner (PA position = 0,0). By simulating hip motion in 1-degree increments, the maximum distance of the PA from the liner center and the direction of its movement was measured (polar coordination system).

Results: The effect of modifying cup and stem anteversion on the direction and distance of the PA's change inside the acetabular liner were different. Stem anteversion influenced the PA position inside the liner more than cup anteversion during sitting, sit-to-stand, squatting, and bending forward ($p = 0.0001$). This effect was evident even when comparing stems with different neck angles ($p = 0.0001$).

Conclusion: Cup anteversion, stem anteversion, and stem neck-shaft angle affected the PA position inside the liner and combined anteversion in different ways. Thus, focusing on cup orientation alone when assessing hip motion during different daily activities is inadequate.

Introduction:

The concept of combined anteversion as the sum of the anatomical acetabular and femoral neck anteversion was originally proposed by McKibbin and known as the “instability index” [1]. The importance of combined anteversion in the prevention of total hip arthroplasty (THA) dislocation has been previously demonstrated [2–9]. The methodology for defining combined anteversion is different in these studies, e.g., intraoperative assessment, radiographic analysis, and mathematical models with computer simulation. In all these studies, anatomical cup and stem anteversions were used to calculate the combined anteversion. The overall perception of the orthopedic community is that as long as combined anteversion is within a certain range, the risk of prosthetic impingement is low. According to this perception, anteversion of one of the implants can be modified to achieve acceptable combined anteversion. This hypothesis will hold true only if the acetabular cup and femoral implant anteversion similarly affect the relative position of the femoral head and the acetabular liner during the range of motion.

The pelvis and femur tilt and rotate with daily activities, and as a result, the functional implant orientation shifts from the static number achieved during surgery. This has been shown in previous investigations of the sagittal pelvic tilt (SPT) and hip-spine relationship [10–18]. The importance of femoral stem anteversion in hip motion is gaining increasing attention. In this study, we investigated the effect of acetabular cup and femoral anteversion mating during hip motion in daily activities. We hypothesized that acetabular cup and femoral anteversion did not equally affect hip motion and combined hip anteversion.

Methods and Materials:

Study setting: This study was conducted using a computer simulation of a THA implant's range of motion. This study was exempt from the institutional review board, as no human subjects were included in the study. This project was conducted under the National Institute of Health (NIH) clinical investigator award.

Computer model development: We developed our computer model using MATLAB 2020a (Simscape–Multibody) (MathWorks MA, USA). A de-identified pelvis and lower body CT scan of a male patient without previous THA or lower extremity surgery was used to import all the bones (pelvis, femur, and tibia) into the model. The THA implant components (a full hemispherical acetabular cup without an elevated rim (best fit diameter = 56 mm), polyethylene liner without an elevated rim (diameter = 36 mm), femoral head (diameter = 36 mm), and a triple-taper cementless stem with three different neck shaft angles (127°, 132°, 135°)] were designed in SolidWorks (Dassault Systèmes SolidWorks Corporation, MA, USA) and imported into the MATLAB model as a computer-aided design (CAD) file. The acetabular cup and liner were placed in the acetabulum, and the stem was placed in the proximal femur based on the anatomical orientation as defined below. Three independent revolute joints at the center of the acetabular cup were used for each of the three hip motions (flexion/extension, abduction/adduction, and internal/external rotation), and one revolute joint at the end of the femur was used for knee flexion.

To simplify the model, readers can imagine passing a pen through the center of the prosthetic femoral neck and the center of the prosthetic femoral head (Figures 1A and 1B). The point on the femoral head where the pen exits is the polar axis (PA). The motion of the femoral head inside the liner produces a motion map, which can be used to study the motion of the hip joint during daily activities (Figure 2). In this model, when the prosthetic head and liner were ideally aligned, the PA faced the center of the liner (coordinates of PA = 0,0). The PA moved toward the edge of the liner with different hip motions. The accurate coordinates of the PA's position at any point in time during each motion can be accurately captured in the polar coordination system. Each motion inside the acetabular liner creates a curved line, as shown in Figure 2, which has a beginning and an end point. The coordinates of the closest position of the PA to the edge of the liner during each motion were captured and used in this study. A straight line connects the center of the acetabular liner and the edge of the liner and passes through the PA's position. The distance of the PA from the center of the acetabular liner along this line was measured in millimeters (mm) and converted to percentage. This coordinate also includes the angle (degrees) of the motion of the polar axis from the center of the acetabular liner during each movement.

Implant orientation: Anatomical acetabular anteversion was calculated relative to the anterior pelvic plane (APP) (Figure 3A). Anatomical abduction was calculated relative to the horizontal plane that connected the hip center of rotation and was perpendicular to the APP. Anatomical femoral anteversion was measured in the posterior femoral condylar plane. The functional acetabular implant orientation was measured relative to the horizontal (ground) and vertical planes (Figures 3B and 3C). If the APP was zero, the APP and vertical planes were parallel, the functional and anatomical cup orientations were similar, and the sagittal pelvic plane was considered to be zero; however, when the pelvis tilted posteriorly, the plane was negative and the anterior tilt was positive. We considered the axial rotation and coronal tilt to be zero to facilitate the measurements.

Motion simulation and model verification: Hip implant motion was simulated in standing, pivoting while standing, sitting, sit-to-stand, bending forward, and squatting motions. The closest position of the PA to the edge of the liner during each motion is shown by colored dots on a sample PA motion map (Figure 4). The motion map has two groups of dots: Group 1 dots are anterior and represent the motions of the hip in standing and pivoting in extension; group 2 dots are posterior and inferior and represent motion with the hip in flexion, including sitting, sit-to-stand, squatting, and bending forward. To verify this model written in MATLAB, an independent model was written in SolidWorks, and the orientation of the implants relative to the reference planes (anterior pelvic plane, horizontal, and vertical planes) and relative to each other were measured and verified in silico.

Variables: The main outcome variables were the maximum distance of the PA from the center for each motion and the angle of movement of the PA inside the acetabular liner. The predictor variables included anatomical cup anteversion (0°–30°) and femoral anteversion (0°–30°) as well as anatomical cup abduction (30°–70°), sagittal pelvic tilt (SPT), measured as the angle between the APP and the vertical plane for each motion, and the femoral stem neck-shaft angle, measured at 1-degree increments (Table 1). We used three prosthetic femoral neck angles (127°, 132°, 135°) with a 36-mm head.

We did not include variables such as different prosthetic femoral head diameters, prosthetic femoral head length, offset, leg length, and depth of implantation of the acetabular cup relative to the acetabular medial wall, as they do not affect the relative motion of the bearing surface and prosthetic head. Different prosthetic head diameters do not change the angle of motion or the position of the PA inside the acetabular liner as a percentage of the distance to the edge of the liner. The purpose of this study was not to study prosthetic or non-prosthetic impingement, but to study the effect of changes in the acetabular cup and femoral stem anteversion on the PA contact points and angular motions. None of the aforementioned variables, size and shape of the pelvis, femoral bone, or offset would affect the relative position of the head and liner as well as the two main outcome variables.

Statistical Analysis:

Modification of the predicting variables by 1° resulted in 118,203 different combinations for our analysis. All variables were continuous and were described as mean, mean difference, standard deviation (SD), and ICC with a 95% confidence interval (CI). Normal distribution of the values was checked by the Shapiro-Wilk normality test for each series of measurements. A multiple linear regression model was used to analyze the effect of the change in the acetabular and femoral anteversion angles as well as other variables on the motion pattern of the hip in different daily activities. The Hosmer-Lemeshow goodness-of-fit test was used to test our logistic regression model. The results of the linear regression model were reported by coefficient, standard error (SE), and confidence interval. The significance level was set at $P < 0.05$. The data were analyzed using Stata 16.0 MP (StataCorp LP, College Station, TX, USA).

Results:

Effect of cup and stem anteversion on the hip motion pattern: The PA motion map with a 135-degree neck-shaft angle stem shows that with the same combined anteversion, the PA position in the cup changes when the acetabular cup and femoral stem anteversion angles are changed separately (Figure 5). This is true with the hip in extension (group 1), showing minimal changes in SPT, and the changes were pronounced in group 2 with hip flexion and increased SPT. This finding is true for the usual cup and stem positions but accentuated with extreme positions (Figure 6). Multiple linear regression performed for each hip motion showed a significant difference between the independent effect of acetabular cup and femoral stem anteversion on PA distance from the center (Table 2) or the angle of PA motion from the center (Table 3). As shown in Table 2, the coefficient for modifying the cup anteversion is higher than the coefficient for modifying the stem anteversion, which means that the PA moves further when we modify the acetabular cup anteversion. This effect is opposite for the angle of motion of the PA inside the liner. As shown in Table 3, modifying the stem anteversion has a significant effect on the angle of motion in movements requiring hip flexion, such as sitting or bending forward, while the opposite is true for standing and pivoting.

Effect of the femoral neck-shaft angle on the motion pattern: Femoral stems with different neck-shaft angles produce different PA motion patterns and change the position of PA inside the polyethylene liner (Figure 7). Stems with a 127-degree neck-shaft angle moved the PA close to the edge of the liner with hip extension (group 1), whereas stems with a 135-degree neck-shaft angle showed motion patterns moving close to the edge of the liner with hip flexion (group 2). Stems with different neck-shaft angles have different motion patterns for both the distance from the center (Table 4) and angle of motion (Table 5). The femoral stems with a low neck-shaft angle will place the PA further from the edge of the acetabular liner with the same amount of stem anteversion in sitting, sit-to-stand, squatting, or bending forward positions. Stems with a lower neck-shaft angle will place the PA closer to the edge of the liner in standing and pivoting positions.

Discussion:

We investigated the effect of modifications of the acetabular cup and femoral stem anteversion and two different stem neck-shaft angles on the motion patterns of the hip joint for postural positions of daily living at the articular level. We used a polar coordination system to measure the position of the polar axis (PA) inside the cup, which provided an accurate assessment of the effects of implant orientation and pelvic tilt. The effects of cup anteversion and stem anteversion are not equivalent; increasing cup anteversion moves the PA position anteriorly in all motions; increasing femoral stem anteversion keeps the PA position close to the cup center with hip flexion, e.g. when sitting and squatting (group 2). Different neck-shaft angles also influence the stem motion patterns, e.g., at the 127-degree neck-shaft angle, the stem was closer to the center of the liner during flexion compared to stems with higher neck-shaft angle. During extension, the PA was closer to the edge of the liner in a pivoting motion using a stem with a 127-degree neck-shaft angle compared to the stem at the 135-degree neck-shaft angle.

Our study had several limitations. Variables such as prosthetic femoral head diameter, femoral head length, offset, leg length, or acetabular implant impaction depth (medialization) were not included; however, these variables did not affect the PA position or the pattern and magnitude of PA motion inside the liner. Our model also limits the lower extremity rotation by assuming that the patient will keep the lower extremity in its neutral position and will not actively internally or externally rotate the leg to more than 10° from its original relaxed position (other than pivoting). The effect of adding internal or external rotation to the lower extremity during different motions is equivalent to widening the anteversion angle range for the femoral stem, which further increased our sample size. For example, if the stem anteversion is 10°, but the patient externally rotates the lower extremity to 10° instead of a neutral position, the functional anteversion of the stem will be 20°. The range of lower extremity anteversion in our model was -10° to +10° in the neutral position, which would change the stem anteversion only up to 10°. We used one pelvis and lower extremity CT scan from a male patient. Regardless of the anatomical shape and size of the pelvis, which is individualized and is affected by sex, the anatomical and functional orientations of the acetabular implant are always measured relative to the anterior pelvic plane. Similarly, the effect of the anterior and posterior pelvic tilt on the functional cup orientation is independent of the size or shape of the pelvis or sex of the patient, as all the measurements are based on the angle between the anterior pelvic plane and horizontal plane. For example, 10° of anterior pelvic tilt is reported in men and women with pelvic structures of different shapes and sizes. We acknowledge that bony coverage and anatomy may influence the surgeons' decisions regarding the size of the implants or the offset to prevent implant or bony impingement; however, these considerations do not affect the relative motions of the head and liner. We did not tilt the pelvis in the sagittal plane to the extremes in this study. The goal of this study was not to investigate impingement and dislocation, so adding a pelvic tilt would not modify the outcome of this study.

The strength of this study lies in its use of femoral stems with different neck-shaft angles, including both sagittal pelvic tilt and modified implant angles in one-degree increments. The model used six position/motions, including hip flexion positions, such as sitting, squatting, and bending forward. This resulted in 118,203 combinations, which provided a very large sample size that allowed us to make generalizable predictions.

Investigators have shown the importance of combined anteversion in hip motion and in the prevention of THA dislocation [2–4,6,19–22]. The common understanding of the orthopedic community is that either the stem or cup position can be changed to maintain combined anteversion. However, the functional implant orientation does not follow the anatomical values because there can be significant differences in pelvic tilt and/or femoral motion among patients who undergo THA [10,11,13–15,23–25]. Many factors such as spinal pathologies, spine fusion surgery, the patient's natural femoral and tibial rotation, coronal and sagittal knee alignment, and the degree of hip flexion contracture can affect the amount of pelvic tilt during different daily motions. Hence, the combined anteversion value must be personalized. In our study, modification of the acetabular implant anteversion angle had a different effect on hip motion as compared to modification of the femoral stem anteversion. Widmer et al. studied the hip motions in a computerized model [2]. They used a stem with a neck-shaft angle of 130°. The range of motion to impingement was studied and the optimal combined anteversion was recommended to be 37° (cup anteversion + 0.7 times the stem anteversion). They recommended a cup abduction angle of 40–45° and cup anteversion angle of 20–28°. In their study, the effects of stems with different neck-shaft angles and of changing the anteversion of each implant separately on the motion pattern were not investigated. We studied the hip motions at the articular surface level and showed that changes in the cup and femoral anteversion have different effects on the hip motion patterns during different daily activities such as sitting, bending forward, and squatting, which are accentuated by different degrees of pelvic tilt, stem neck-shaft angles, and functional femoral anteversion (regardless of anatomical femoral anteversion) among patients. As a result, the formulas based on the old definition of combined anteversion may be inadequate.

With the increased use of robotics and advanced technology in the operating room, preoperative computer simulation of the safe zone should take into account the native femoral anteversion and femoral implant orientation in addition to the orientation of the acetabular cup. Any computer simulation or operative technique that concentrates on the orientation of the acetabular implant alone may not reliably optimize implant mating. The intraoperative anteversion angle of the femoral broach may not be the same as that predicted using computer simulation models, so the surgeon should make the final assessment intraoperatively.

Conclusion:

The acetabular cup, femoral anteversion, and stem neck-shaft angle affect hip motion and the combined anteversion. Focusing on the acetabular cup orientation alone to determine a safe hip implant zone is inadequate. Computer simulations of THA motions used for recommending optimal implant orientation should consider the femoral stem design as well as the anatomical and functional femoral stem anteversion angles during different daily activities. As the effects of acetabular cup and stem anteversion on the motions differ with hip flexion and extension and with stem neck-shaft angles, we cannot use a universal formula to calculate the optimum combined anteversion.

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Table 1: This table shows the range for the study variables used for computer simulation and motion analysis.

Study variables	Range
Cup abduction angle	30° to 70°
Cup anteversion angle	0° to 30°
Femoral stem anteversion angle	0° to 30°
Standing pelvic tilt angle	-10° to 10°
Sitting pelvic tilt angle	0° to -30°
Sitting to standing pelvic tilt angle	-10° to 20°
Bending pelvic tilt angle	20° to 55°
Squatting pelvic tilt angle	-5° to 30°
Pivoting pelvic tilt angle	-10° to 10°

Table 2: Results of multiple linear regression to compare the effect of the cup anteversion and stem anteversion on the polar axis distance from the center of the polyethylene during different daily activities. Positive coefficient means that the polar axis is moving toward the edge of the acetabular liner while negative coefficient means that the polar axis is moving away from the edge of the liner and toward the center of the liner.

Motion	Variable	Coefficient	Standard error	95% confidence interval	P value
Standing	Cup anteversion	0.513	0.00075	0.512, 0.515	p<0.00001
	Stem anteversion	0.494	0.00075	0.493, 0.496	
Pivoting while standing	Cup anteversion	0.294	0.0002	0.294, 0.295	p<0.00001
	Stem anteversion	0.269	0.0002	0.269, 0.27	
Sitting	Cup anteversion	-0.391	0.0015	-0.394, -0.388	p<0.00001
	Stem anteversion	-0.221	0.0015	-0.224, 0.218	
Sit-to-stand	Cup anteversion	-0.378	0.0004	-0.379, -0.377	p<0.00001
	Stem anteversion	-0.233	0.004	-0.234, -0.232	
Bending forward	Cup anteversion	-0.494	0.0009	-0.496, -0.492	p<0.00001
	Stem anteversion	-0.369	0.0009	-0.371, -0.367	
Squatting	Cup anteversion	-0.347	0.0004	-0.348, -0.346	p<0.00001
	Stem anteversion	-0.211	0.0004	-0.212, -0.21	

Table 3: Results of multiple linear regression to compare the effect of the cup anteversion and stem anteversion on the angle of the motion of the polar axis from the center of the polyethylene during different daily activities. Higher coefficient means a stronger effect of the change on the polar axis angle of motion inside the acetabular liner. Pelvic tilt angle is considered in determining the superior and inferior edge of the liner as well as the angle of the PA movement in this model.

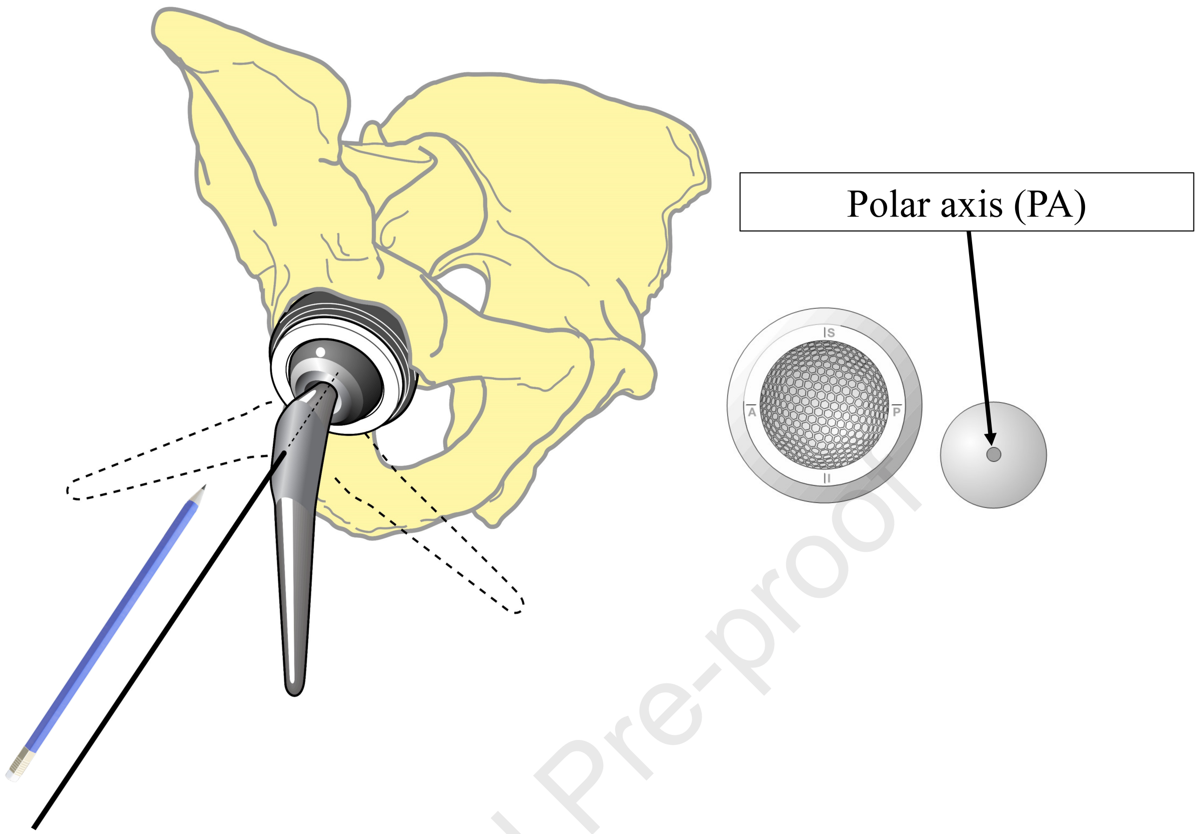
Motion	Variable	Coefficient	Standard error	95% confidence interval	P value
Standing	Cup anteversion	-0.446	0.004	-0.454, -0.43	p<0.00001
	Stem anteversion	-0.224	0.004	-0.232, -0.216	
Pivoting while standing	Cup anteversion	-0.465	0.0008	-0.467, 0.463	p<0.00001
	Stem anteversion	-0.406	0.0008	-0.408, -0.404	
Sitting	Cup anteversion	2.81	0.0198	2.779, 2.857	p<0.00001
	Stem anteversion	2.89	0.0198	2.854, 2.932	
Sit-to-stand	Cup anteversion	-1.053	0.001	-1.055, -1.051	p<0.00001
	Stem anteversion	0.876	0.001	0.874, 0.878	
Bending forward	Cup anteversion	0.307	0.152	0.278, 0.337	p<0.00001
	Stem anteversion	1.68	0.152	1.654, 1.714	
Squatting	Cup anteversion	-1.044	0.0009	-1.046, -1.042	p<0.00001
	Stem anteversion	0.849	0.0009	0.848, 0.851	

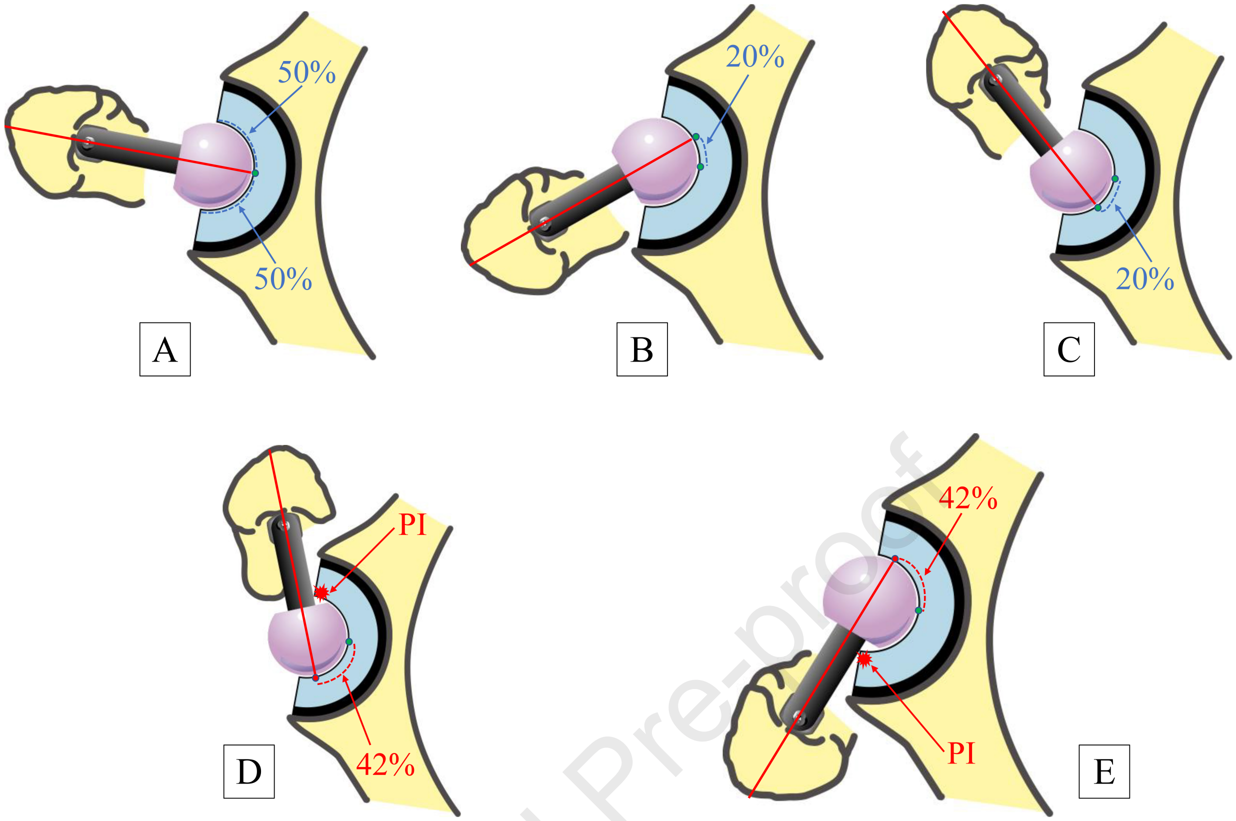
Table 4: Results of multiple linear regression to compare the effect of the femoral stem neck-shaft angle on the distance of the polar axis from to the center of the polyethylene liner during different daily activities. The stem with a 127˚ is the reference stem and the coefficient and p values show the difference between the stems with high neck-shaft angle relative to the stem with 127˚ stem. Positive coefficient means that polar axis is moving toward the edge of the acetabular liner while negative coefficient means that the polar axis is moving away from the edge of the liner and toward the center of the liner.

Motion	Variable	Coefficient	Standard error	95% confidence interval	P value
Standing	132˚ neck angle	-1.082	0.165	-1.114, -1.05	p<0.00001
	135˚ neck angle	-1.48	0.165	-1.513, -1.448	p<0.00001
Pivoting while standing	132˚ neck angle	-1.238	0.005	-1.25, -1.22	p<0.00001
	135˚ neck angle	-2.002	0.005	-2.014, -1.99	p<0.00001
Sitting	132˚ neck angle	1.483	0.0331	1.418, 1.548	p<0.00001
	135˚ neck angle	2.843	0.0331	2.778, 2.9	p<0.00001
Sit-to-stand	132˚ neck angle	2.6	0.0107	2.583, 2.625	p<0.00001
	135˚ neck angle	4.09	0.0107	4.075, 4.117	p<0.00001
Bending forward	132˚ neck angle	2.231	0.0209	2.19, 2.272	p<0.00001
	135˚ neck angle	3.792	0.0209	3.751, 3.833	p<0.00001
Squatting	132˚ neck angle	2.518	0.01	2.498, 2.538	p<0.00001
	135˚ neck angle	3.944	0.01	3.924, 3.964	p<0.00001

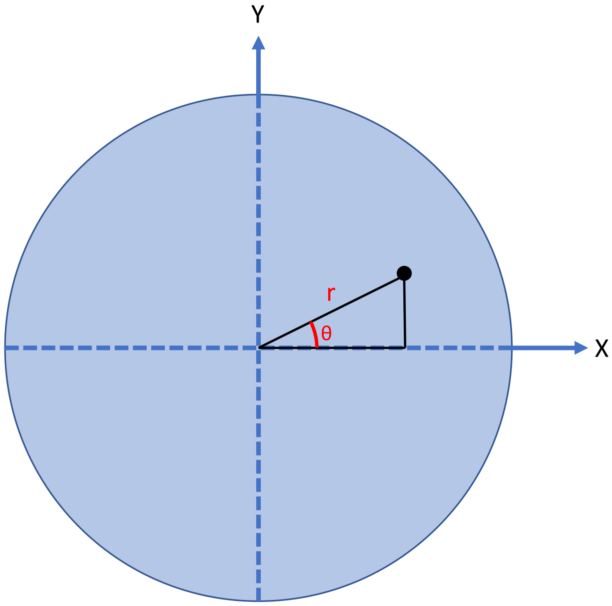
Table 5: Results of multiple linear regression to compare the effect of the femoral stem neck-shaft angle on the angle of the polar axis motion relative to the center of the polyethylene liner during different daily activities. The stem with a 127˚ is the reference stem and the coefficient and p values show the difference between the stems with high neck-shaft angle relative to the 127˚ stem. A higher coefficient means a stronger effect in the change f the polar axis angle of motion inside the acetabular liner. Pelvic tilt angle is considered in determining the superior and inferior edge of the liner as well as the angle of the PA movement in this model.

Motion	Variable	Coefficient	Standard error	95% confidence interval	P value
Standing	132˚ neck angle	-10.17	0.088	-10.34, -0.998	p<0.00001
	135˚ neck angle	-16.713	0.088	-16.887, -16.54	p<0.00001
Pivoting while standing	132˚ neck angle	-4.513	0.019	-4.551, -4.475	p<0.00001
	135˚ neck angle	-7.355	0.019	-7.393, -7.318	p<0.00001
Sitting	132˚ neck angle	-26.34	0.435	-27.195, -25.488	p<0.00001
	135˚ neck angle	-32.88	0.435	-33.741, -32.033	p<0.00001
Sit-to-stand	132˚ neck angle	2.976	0.023	2.931, 3.021	p<0.00001
	135˚ neck angle	4.579	0.023	4.534, 4.625	p<0.00001
Bending forward	132˚ neck angle	-15.867	0.334	-16.523, -15.21	p<0.00001
	135˚ neck angle	-12.437	0.344	-13.094, -11.781	p<0.00001
Squatting	132˚ neck angle	2.681	0.0199	2.642, 2.72	p<0.00001
	135˚ neck angle	4.139	0.0199	4.1, 4.17	p<0.00001


Polar axis (PA)
IS
A
P
II


50%
50%
A
20%
B
20%
C
PI
42%
D
42%
PI
E

Polar Coordinate System



(r: distance, θ: angle of motion)

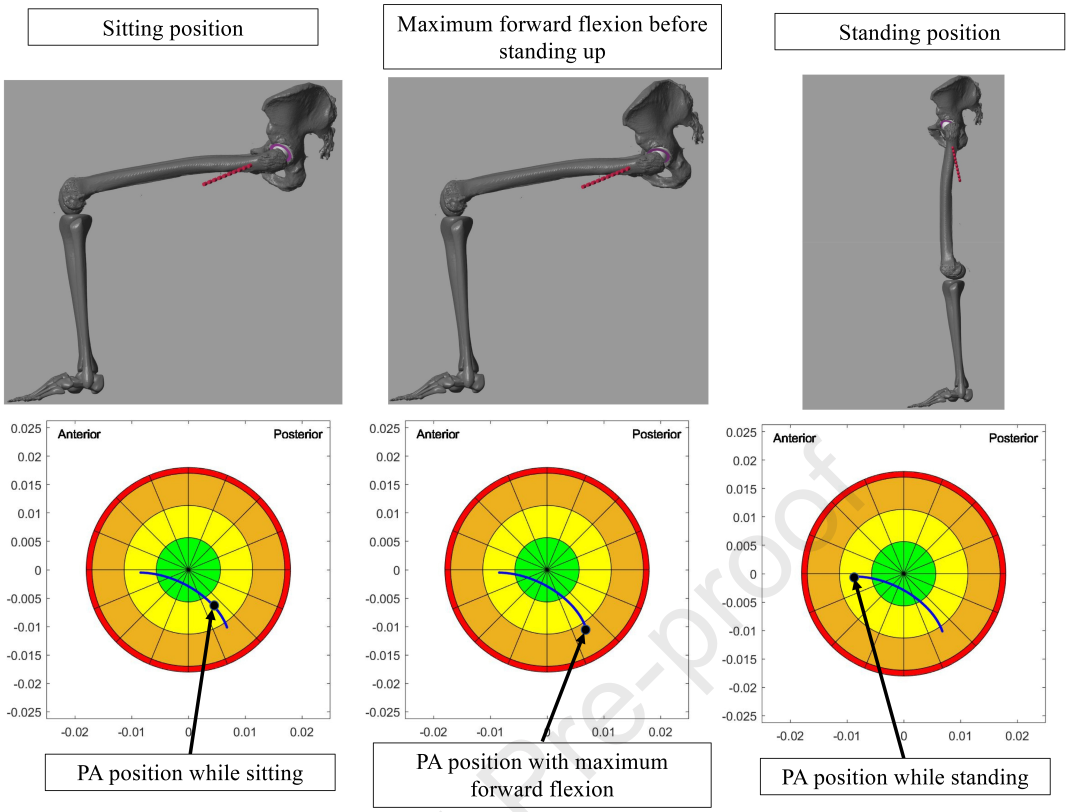

Sitting position
Maximum forward flexion before standing up
Standing position
Anterior
Posterior
PA position while sitting
PA position with maximum forward flexion
PA position while standing

Figure Legend:

Figure 1A: This figure shows how the motions of the femoral head inside the polyethylene liner is captured. A line goes through the center of the femoral neck and prosthetic head. The place where the line exits from on the prosthetic femoral head is polar axis (PA). The motions of PA inside the polyethylene liner is captured during simulation.

Figure 1B: This figure shows the polar axis and its motions inside the liner. Polar axis is aligned with the center of the liner (A). It moves anteriorly and posteriorly during internal and external rotation without impingement (B and C). It moves anteriorly and posteriorly with internal and external rotation until the impingement occurs (D and E). During these motions, the position of the PA relative to the center of the liner along a straight line drawn from the center of the liner to the edge of the liner that passes through the position of the PA. The distance of the PA relative to the center or edge of the liner can be measured in millimeter or converted to percentage as well.

Figure 1C: This figure shows the polar coordinate system. "R" represents the distance from the center and the θ represents the angle of the motion of the polar axis relative to the center.

Figure 2: This figure shows sit-to-stand motion with the map. The position of the polar axis (PA) inside the liner is shown in the sitting position. With maximum anterior pelvic tilt and the hip flexion right before standing, the PA moves closer to the edge of the polyethylene (maximum risk for impingement and dislocation). After standing, the PA moves inside the polyethylene to the new position. The coordinates of these positions is captured with less than 1-degree accuracy during simulation.

Figure 3A: Anterior pelvic plane (APP) is defined as a plane connecting the anterior superior iliac spines to the pubic symphysis.

Figure 3B: Anatomical femoral anteversion was measured off the posterior femoral condylar plane (A). Functional femoral anteversion was measured relative to the vertical plane in standing (B).

Figure 3C: Functional femoral anteversion was measured relative to the horizontal plane in sitting position.

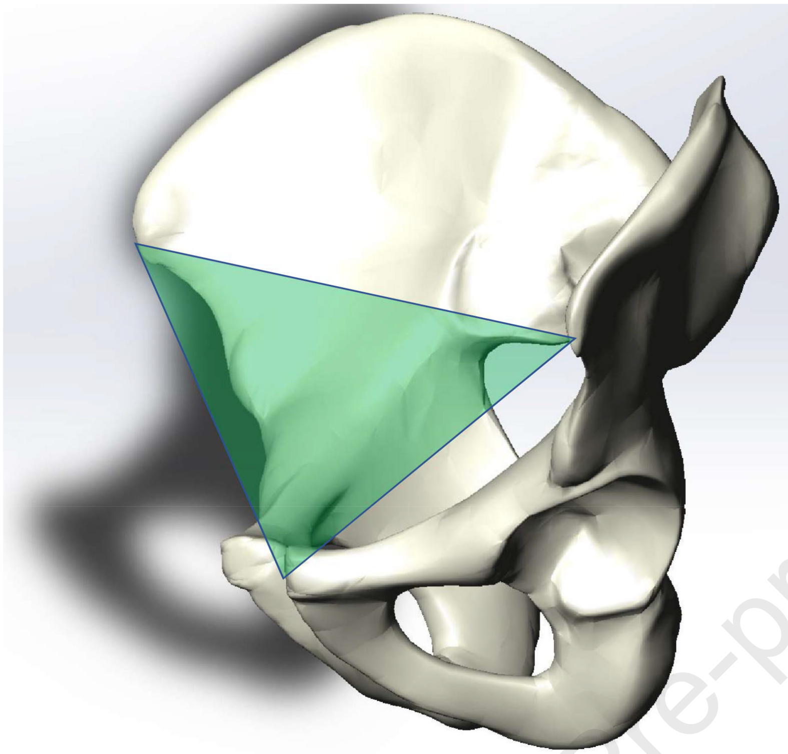
Figure 4: A sample motion map for 2 positions (standing and sitting) and 4 motions (pivoting, sit-to-stand, squatting, bending forward) is presented in this figure. Group-1 represents standing and pivoting which occur with hip in extension. Group-2 represents sitting, sit-to-stand, squatting and bending forward to pick up an object which occur with hip in flexion.

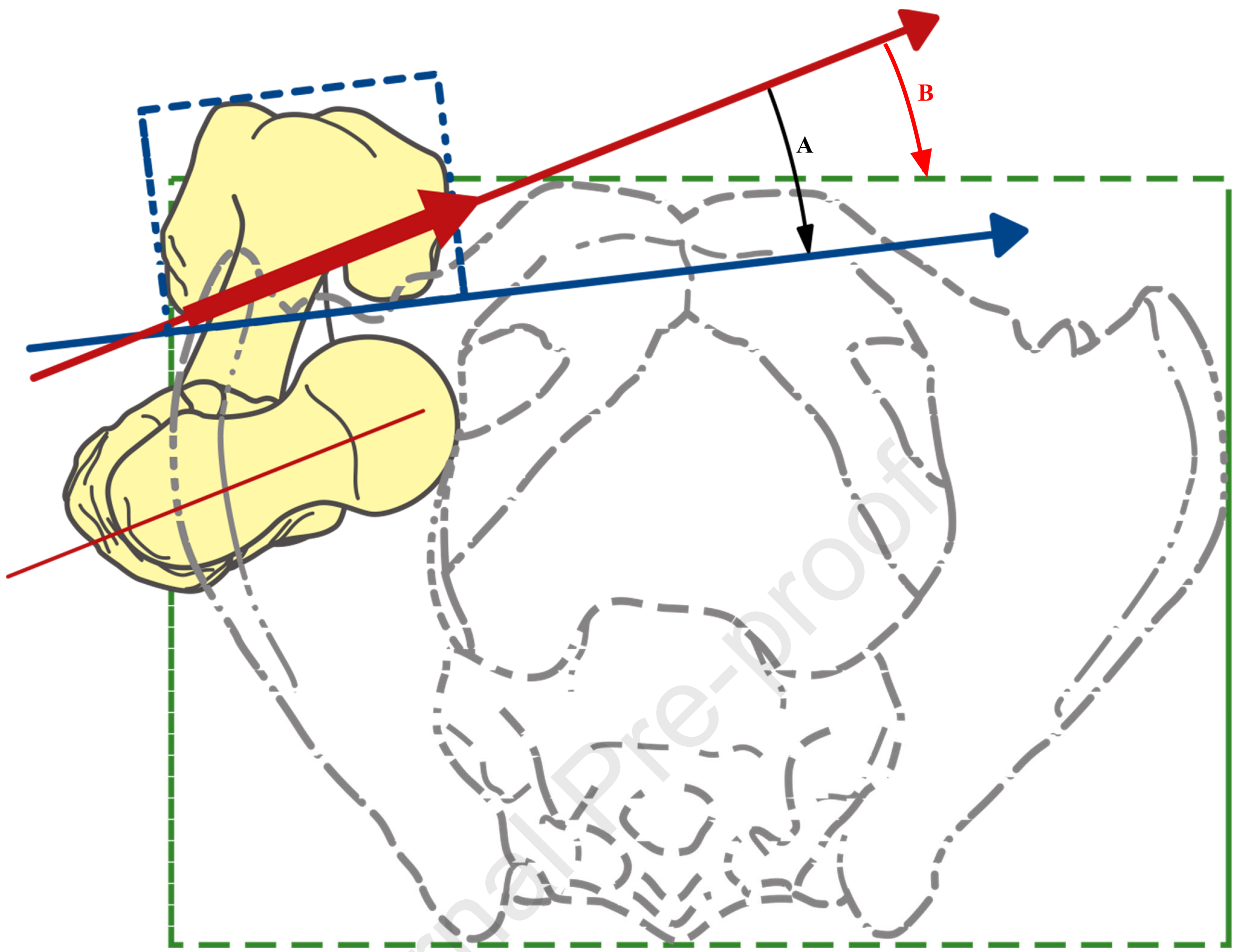
Figure 5: This figure shows the motion map comparing the effect of the acetabular cup and femoral stem anteversion modification on the hip motions. Combined anteversion is defined as the sum of anatomical acetabular cup anteversion and femoral anteversion. Despite resulting in the same combined anteversion, modification of the acetabular cup and femoral stem results in different motion patterns in the hip joint.

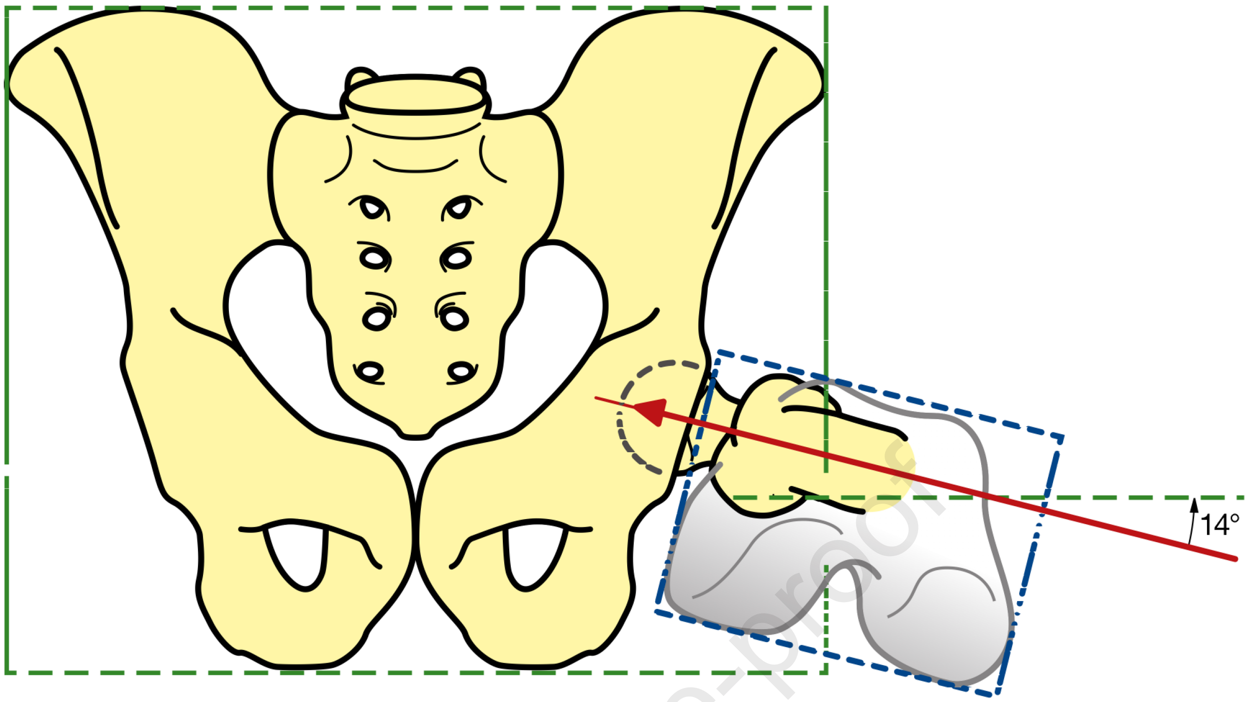
Figure 6: Figure 6 shows eight different combinations of the cup and femoral anteversion which would provide a combined anteversion of 45˚. As seen in this figure, even when the implant anteversion is within a range that orthopaedic surgeons would consider acceptable for THA, the pattern of the PA motions inside the polyethylene liner is not similar.

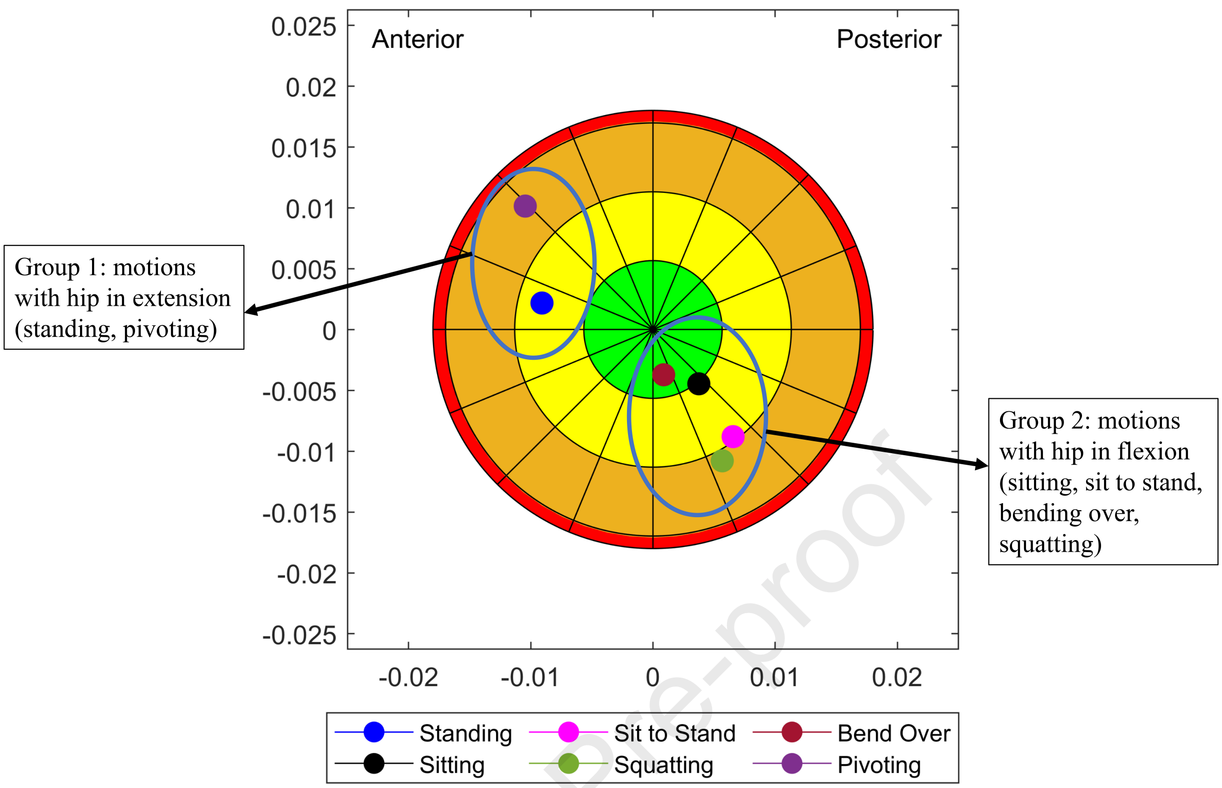
Figure 7: The effect of femoral stem neck-shaft angle change on the hip motions is presented in this figure. Stems with smaller femoral neck-shaft angle move the polar axis (PA) further away from the edge of the polyethylene in sit-to-stand, squatting or bending forward as compared to

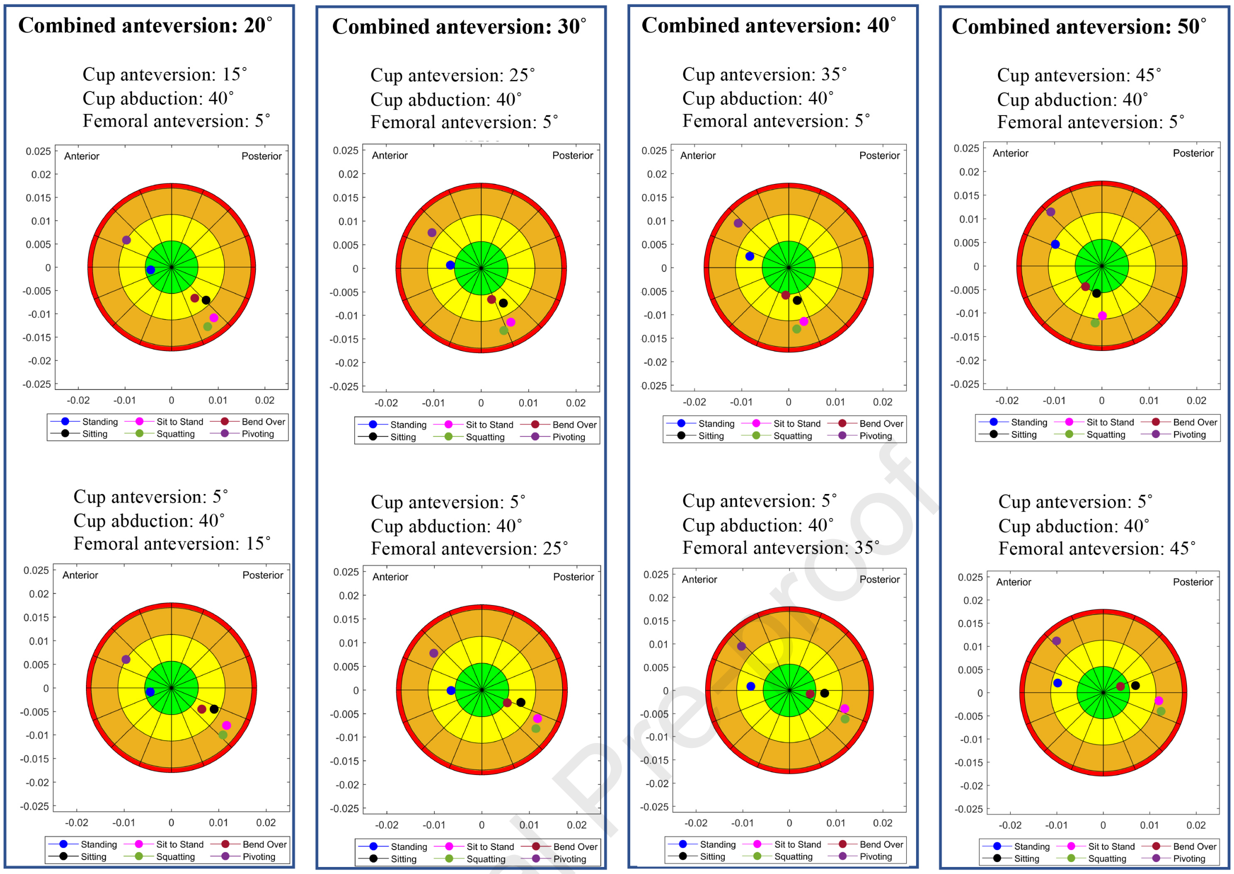
the stems with larger femoral neck-shaft angle. These stems will move the PA closer to the edge of the polyethylene in pivoting and standing compared to the stems with larger neck-shaft angle.

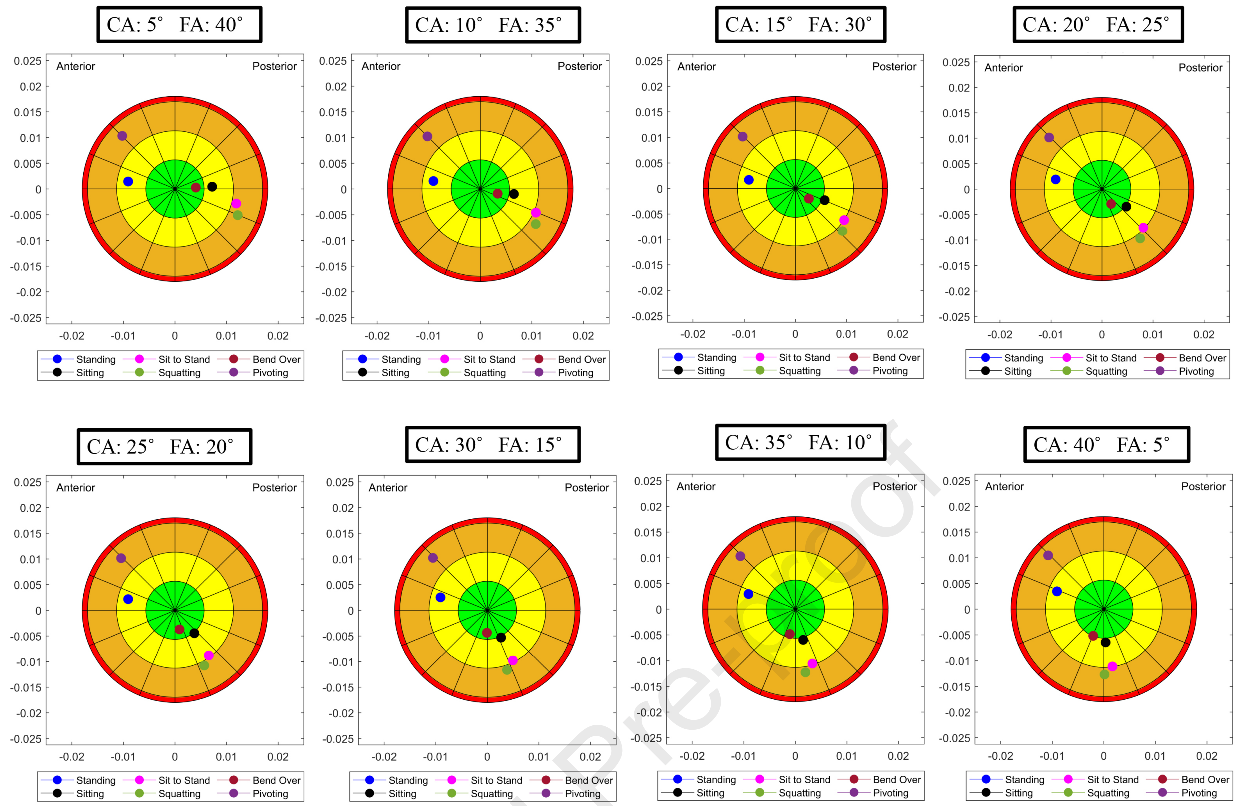



A
B


14°

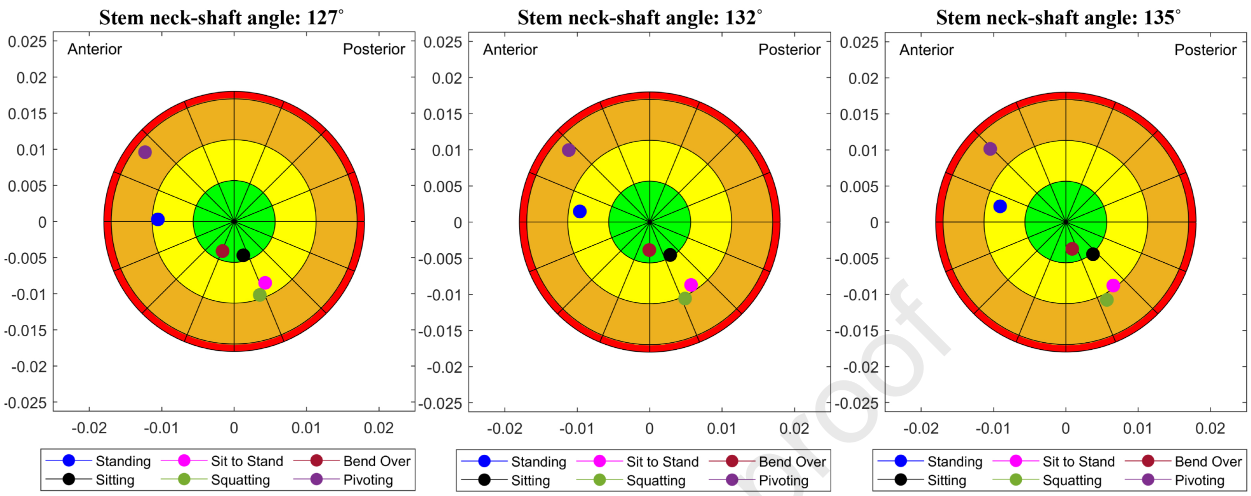

0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.02
-0.01
0
0.01
0.02
Anterior
Posterior
Group 1: motions with hip in extension (standing, pivoting)
Group 2: motions with hip in flexion (sitting, sit to stand, bending over, squatting)
Standing
Sitting
Sit to Stand
Squatting
Bend Over
Pivoting


Combined anteversion: 20°
Cup anteversion: 15°
Cup abduction: 40°
Femoral anteversion: 5°
Cup anteversion: 5°
Cup abduction: 40°
Femoral anteversion: 15°
Combined anteversion: 30°
Cup anteversion: 25°
Cup abduction: 40°
Femoral anteversion: 5°
Cup anteversion: 5°
Cup abduction: 40°
Femoral anteversion: 25°
Combined anteversion: 40°
Cup anteversion: 35°
Cup abduction: 40°
Femoral anteversion: 5°
Cup anteversion: 5°
Cup abduction: 40°
Femoral anteversion: 35°
Combined anteversion: 50°
Cup anteversion: 45°
Cup abduction: 40°
Femoral anteversion: 5°
Cup anteversion: 5°
Cup abduction: 40°
Femoral anteversion: 45°
Anterior
Posterior
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.02
-0.01
0
0.01
0.02
Standing
Sitting
Sit to Stand
Squatting
Bend Over
Pivoting



CA: 5° FA: 40°
CA: 10° FA: 35°
CA: 15° FA: 30°
CA: 20° FA: 25°
CA: 25° FA: 20°
CA: 30° FA: 15°
CA: 35° FA: 10°
CA: 40° FA: 5°
Anterior
Posterior
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
Standing
Sit to Stand
Bend Over
Sitting
Squatting
Pivoting

Combined anteversion: 45˚
Cup anteversion: 25˚
Femoral anteversion: 20˚
Cup abduction: 40˚



INDIVIDUAL CONFLICT OF INTEREST STATEMENT

American Association of Hip and Knee Surgeons

(Adopted from the American Academy of Orthopaedic Surgeons disclosure statement)

The following form **must be filled out completely and submitted by each author (example, 6 authors, 6 forms). All items require a response. If there is no relevant disclosure for a given item, enter "*None*."**

Manuscript Title: Is Combined Anteversion Equally Affected by Acetabular Cup and Femoral Stem Anteversion?

1. Royalties from a company or supplier (The following conflicts were disclosed)

None

2. Speakers bureau/paid presentations for a company or supplier (The following conflicts were disclosed)

None

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9. Board member/committee appointments for a society (The following conflicts were disclosed)

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Kunj Patel 10/25/2020

Author Name (Print or Type) Author Signature Date

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Smith&Nephew, Intelijoint

3C. Unpaid consultants for a company or supplier (The following conflicts were disclosed)

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Intelijoint, Gauss Surgical, PSI

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Ran Schwarzkopf	*Ran Schwarzkopf*	10/25/2020
Author Name (Print or Type)	Author Signature	Date

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