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Clinical importance and sex differences of the femoral anteversion angle

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ABSTRACT

Introduction: The femoral angle of anteversion (FAA) is responsible for the medial and anterior direction of femoral neck and, therefore, the femoral head toward the acetabulum. The aim of this study was to determine the difference in FAA between male and female samples and correlation between the FAA and biomechanically relevant parameters and to provide a review of relevant clinical features related to FAA.

Methods: We included 100 human dry femora and analyzed FAA, angle of inclination (AI), femoral head diameter (FHD), femoral biomechanical length (FBL), and linear condylar parameters (LCD) (epicondylar breadth width [EBW], lateral condyle depth, and medial condyle depth [MCD]). The measurements were made using a goniometer, sliding calipers, and pieces of colored string.

Results: Mean FAA values were 9.84±7.97° and 8.72±8.23° for the male and female samples, respectively ($p<0.05$). FAA and AI in both male and female correlated negatively (–0.076); there was a positive correlation between FAA and FHD (0.069), FAA and FBL (0.072), and FAA and EBW (0.029), while the correlation was negative between FAA and LCD (–0.072) and FAA and MCD (–0.063).

Conclusion: The difference in FAA between male and female femora was found to be significant. This finding may help better understanding such as hip impingement, total hip arthroplasty failure, and design of femoral endoprosthesis parts.

Keywords: Femoral angle of anteversion; angle of inclination; angle of inclination; femoral head diameter; femoral biomechanical length; linear condylar parameters; epicondylar breadth width; lateral condyle depth; medial condyle depth

INTRODUCTION

Femoral angle of anteversion (FAA) or angle of inclination (AI) in the horizontal plane is the angle that defines the deviation of the femoral neck anteriorly from the axis that passes through the posterior most points of the femoral epicondyles (1). The value of FAA ranges from 4 to 20° with the average value being 12° (2). The value is subjected to multiple categories of variations including age, sex, pathological and physiological alterations, and genetic traits; furthermore, bone shapes and structures adapt to the muscle and reaction forces they experience during everyday movements. The onset of independent walking, at approximately 12 months, represents the first postnatal exposure of the lower limbs to

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the large forces associated with bipedal movements, and accordingly, earlier walking is associated with greater bone strength (3). Although the concept was first recorded in writing by anatomist Julius Wolff, humans through the ages have noticed the femoral anterior deviation as evidenced by paintings that depict human walking in the caves of central France or Da Vinci's sketches (4). FAA is anatomically and biomechanically important in the constitution of the hip joint since it is responsible for the medial and anterior direction of femoral neck and, therefore, the femoral head toward the acetabulum (1,5). The superior orientation is due to the AI in the frontal plane (collodiaphysial angle or neck-shaft angle, AI). Consequently, the axis of the acetabulum is pointed inferiorly, lateraly, and anteriorly at the same time leaving a portion of relatively round femoral head outside the acetabulum (1,2). Such relationships provided us with stable and unstable positions of the hip, with abduction, internal rotation, and extension being the stable position due to the better congruence between the bodies of the diarthrodial joint (1,6). These statements are pivotal in understanding hip dislocations and repositions (5). Although it has been postulated that such an orientation alters the force load of the hip and causes faster occurrence of coxarthrosis, those claims appear to be false in the sense that major fluctuations of the force load have not been recorded during walking even though such an occurrence is to be expected in the frontal plane regarding the AI (7,8). A classification has been proposed regarding the joint space narrowing due to FAA variations, and as such, we recognize bicentric and monocentric joints (5,7). Monocentric joints make only one point of contact with the acetabulum, while bicentric joints make two or more contacts (7). Such categorizations are understandable since FAA plays a explanatory role in hip joint surface coaptations (6). The static load force is the resultants of the main weight-bearing force and its counterforce that consists of abductor muscle actions; the resultant force vector is pointed from proximal and posterior toward distal and anterior (6). The axis of the effective surface of the resultant vector is not in the same axis as the resultant line due to AI and FAA differences making an obtuse angle between the two. As such, the angles around the proximal femur determine the two different coaptation forces that determine the static morphology of the joint space (6). These findings are relative to other morphologic and, therefore, biomechanical characteristics, such as ligament tension, muscle volume, and even negative atmospheric pressure (1-3). It is still not clear whether the FAA provides us with a biomechanical advantage in regard to our evolutionary ancestors since there is no doubt that we inherited the same trait but are subjected to different biomechanical forces than our quadrupedal counterparts (9). Such a trait could be rudimentary or could be of benefit in the sense that it ensures verticalization of the AI and, therefore, provides us with a stable turning momentum allowing greater gait stabilization (9). The imaging of the FAA is particularly relevant, seeing that it is still a point of research whether the current imaging methods truly reflect the FAA values (10-12). FAA changes could present with false radiograph interpretation (13,14). Endoprosthetic surgery is a field where new prosthesis designs are a necessity, seeing that post-implantation periods are long and hard to follow leaving us with theoretical knowledge to design prostheses (15). One of the subjects of interest is the FAA since different authors have diverging opinions whether to allow prostheses with physiologic values for better mobility or to go with the 0° option for stability (16,17). Such factors raise the question of sex-specific prostheses, seeing that the FAA variers between sexes. Sex differences regarding FAA are relevant for surgical procedure planning and rehabilitation, seeing that female hips are more anteverted and require detailed preoperative assessment and cautious rim trimming for optimal weight bearing (18). Other pathological alterations such as cerebral palsy are also linked with the FAA (19,20). Anthropology is another field with the utmost importance for proximal femur morphometrics, seeing that the globalization processes and migrations diminish the value of pre-existing anthropologic databases where population and race-specific morphometric values have larger variations (21). Due to such statements, new and comprehensive databases should be made and updated regularly.

The aim of this study was to determine the difference in femoral anteversion angles (AAs) between male and female samples, to ascertain correlation between the femoral AA and certain biomechanically relevant parameters, and to provide a review of relevant clinical features regarding the femoral AA, seeing that a large spectrum of particularly important topics in both orthopedics and traumatology, including total hip arthroplasty due to degenerative or traumatologic etiologies, and varying topics in neuroorthopaedics, most of all cerebral palsy.

MATERIALS AND METHODS

Materials

We examined 100 adult dry human femora, 52 of which were male and 48 female. The femora were taken from the Department of Anatomy, Medical School, University of Sarajevo. Femora with visible pathological alterations were excluded from the study.

Measured parameters

The measured parameters were the FAA and AI, femoral head diameter (FHD), femoral biomechanical length (FBL), and linear condylar parameters (LCD) (epicondylar breadth width [EBW], lateral condyle depth and medial condyle depth). The parameters were chosen as biomechanically relevant according to Pauwels or based on other articles (6,19,20). The measurements were made according to Martin, Shrimathi, and Kirby using a goniometer, sliding calipers, and pieces of colored string (13,22,23). All the values were measured 3 times and the mean value was recorded.

Statistical methods

We determined descriptive statistical measures and correlation methods and ascertained the difference between male and female femora using paired t-tests using the IBM SPSS and XLSTAT program. $p<0.05$ was considered statistically significant. A positive correlation (Pearson) was determined as $r\leq1$ while a verbal scale according to Evans was used with 0.00–0.19 marked as "very weak," 0.20–0.39 as "weak," 0.40–0.59 as "moderate," 0.60–0.79 as "strong," and 0.80–1 as "very strong (24)."

RESULTS

The FAA mean in both samples was 9.31±8.07° with the minimum value (including retroversion or negative values) being −15° and maximum 20° (Tables 1 and 2). The correlation coefficient between FAA and AI in both samples was –0.076, and the correlation was marked as a very weak negative correlation ($p<0.5$). The FAA and FHD in both the samples correlate positively but very weakly with a correlation coefficient of 0.069, and the correlation between FBL and FAA was also labeled as very weak with a correlation coefficient of 0.072 ($p<0.5$). EBW and FAA in both samples correlate negatively with a correlation coefficient of –0.029 which is regarded as very weak ($p<0.5$) (Table 3). Linear anteroposterior parameters in both samples as well as their mediolateral counterpart correlate negatively with the FAA with the correlation coefficients –0.072 for LCD and –0.063 for Medial Condyle Depth (MCD) ($p<0.5$). For the male samples, the mean was 9.84±7.97° with the minimum value −15° and maximum 20° (Table 4). The correlation coefficient between FAA and AI of male samples was –0.0127 and between FAA and FHD –0.065, both resulting in a very weak negative correlation ($p<0.5$). The FAA in male samples

TABLE 1. Descriptive statistics for male samples

Statistic	FAA	AI	FHD	EBW	LCD	MCD	FBL
Number of observations	52	52	52	52	52	52	52
Minimum	-15.000	13.000	44.000	76.000	54.000	51.000	39.000
Maximum	2.0000	14.0000	55.000	92.000	74.000	76.000	48.500
1st quartile	8.750	116.500	46.000	78.750	6.1750	58.750	42.150
Median	11500	12.0000	47.000	82.500	65.000	62.000	43.200
3rd quartile	13.250	125.000	5.0000	85.000	67.000	64.000	44.625
Mean	9.846	119.596	47.962	82.288	64.308	61.654	43.490
Variance (n-1)	63.544	272.442	9.253	17.347	19.276	22.584	4.544
Standard deviation (n-1)	7.971	16.506	3.042	4.165	4.390	4.752	2.132

FAA: Femoral angle of anteversion; AI: Angle of inclination; FHD: Femoral head diameter; EBW: Epicondylar breadth width; LCD: Linear condylar parameter; MCD: Medial Condyle Depth; FBL: Femoral biomechanical length correlates positively with the FBL with a correlation coefficient of 0.060 marked as very weak (p<0.5). A negative correlation was established between FAA and EBW in the male samples and was labeled as weak with a value of –0.239 (p<0.5). A weak negative correlation was established between FAA, LCD, and MCD with the values –0.243 and –0.193. The female samples had a mean of 8.72±8.23° and a minimum value of –15° and maximum value of 20° (Table 5). They correlated positively but weakly with the AI with a correlation coefficient of 0.052 (p<0.5). Very weak positive correlation was seen between FAA and FHD female samples with a correlation coefficient of 0.169, and FBL also correlated very weakly with the FAA in female samples with a correlation coefficient of 0.033 (p<0.5). Positive, although very weak, correlation was established with FAA, LCD, and MCD with correlation coefficients of 0.018 and 0.003 (p<0.5). Epicondylar breadth width correlated negatively. The difference between

TABLE 2. Descriptive statistics for female samples

Statistic	FAA	AI	FHD	EBW	LCD	MCD	FBL
Number of observations	48	48	48	48	48	48	48
Minimum	−15.000	105.000	36.000	62.000	5.0.000	49.000	37.000
Maximum	20.000	130.00	45.000	80.000	67.000	65.000	44.000
1st Quartile	8.750	117.000	40.750	70.000	56.000	52.750	39.875
Median	10.000	120.000	42.000	71.000	59.500	56.000	40.500
3rd Quartile	13.000	125.000	43.000	75.000	62.250	60000	41.550
Mean	8.729	120.688	41.917	71.896	59.125	56.896	40.750
Variance (n-1)	67.776	33.794	4.461	14.819	15.218	19.414	2.615
Standard deviation (n-1)	8.233	5.813	2.112	3.850	3.901	4.406	1.617

FAA: Femoral angle of anteversion; AI: Angle of inclination; FHD: Femoral head diameter; EBW: Epicondylar breadth width; LCD: Linear condylar parameter; MCD: Medial Condyle Depth; FBL: Femoral biomechanical length

TABLE 3. Correlation matrix for both samples

Variables	FAA	AI	FHD	EBW	LCD	MCD	FBL
FAA	1	−0.076	0.069	0.029	0.072	0.063	0.073
AI	−0.076	1	0.045	0.036	0.047	−0.081	0.039
FHD	0.069	0.045	1	0.785	0.679	0.587	0.753
EBW	−0.029	−0.036	0.785	1	0.676	0.538	0.652
LCD	−0.072	0.047	0.679	0.676	1	0.758	0.634
MCD	−0.063	−0.081	0.587	0.538	0.758	1	0.547
FBL	0.073	0.039	0.753	0.652	0.634	0.547	1

FAA: Femoral angle of anteversion; AI: Angle of inclination; FHD: Femoral head diameter; EBW: Epicondylar breadth width; LCD: Linear condylar parameter; MCD: Medial Condyle Depth; FBL: Femoral biomechanical length

TABLE 4. Correlation matrix for male samples

Variables	FAA	AI	FHD	EBW	LCD	MCD	FBL
FAA	1	−0.0.127	−0.065	−0.239	−0.243	−0.0.193	0.060
AI	−0.127	1	0.087	−0.125	−0.063	− 0.054	−0.063
FHD	−0.065	0.087	1	0.509	0.665	0.474	0.668
EBW	−0.239	−0.125	0.509	1	0.555	0.525	0.494
LCD	−0.243	−0.063	0.665	0.555	1	0.754	0.623
MCD	−0.193	−0.054	0.474	0.525	0.754	1	0.349
FBL	0.060	−0.063	0.668	0.494	0.623	0.349	1

FAA: Femoral angle of anteversion; AI: Angle of inclination; FHD: Femoral head diameter; EBW: Epicondylar breadth width; LCD: Linear condylar parameter; MCD: Medial Condyle Depth; FBL: Femoral biomechanical length

TABLE 5. Correlation matrix for female samples

Variables	FAA	AI	FHD	EBW	LCD	MCD	FBL
FAA	1	0.053	0.161	−0.026	0.006	−0.012	0.014
AI	0.053	1	0.289	0.409	0.080	−0.147	0.167
FHD	0.161	0.289	1	0.402	0.221	0.308	0.411
EBW	−0.026	0.409	0.402	1	0.412	0.050	0.201
LCD	0.006	0.080	0.221	0.412	1	0.585	0.224
MCD	−0.012	−0.147	0.308	0.050	0.585	1	0.440
FBL	0.014	0.167	0.411	0.201	0.224	0.440	1

FAA: Femoral angle of anteversion; AI: Angle of inclination; FHD: Femoral head diameter; EBW: Epicondylar breadth width; LCD: Linear condylar parameter; MCD: Medial Condyle Depth; FBL: Femoral biomechanical length

male and female samples was labeled as statistically significant ($p<0.05$).

DISCUSSION

This study was performed to ascertain the difference between the FAA in male and female femora and to see how biomechanically rationalized as well as pathologically related parameters correlate with the FAA. This study was performed on dry femora because adequate measurement of the femoral AA is still debated and it seems that morphometric measurement is still the golden standard although clinically the techniques are naturally obsolete (10-14). The downfall of this study is the uncertain bone age, although we knew that the femora are from adult individuals and we cannot determine their accurate age. We found that the difference in AAs between male and female femora was significant and it correlates well with other studies (8,9,13,23). Hetsroni et al. determined the difference between the femoral AAs in male and female samples using imaging methods from their hip arthroscopy registers to ascertain the values relevant for hip impingement syndromes (18). Nakahara et al. measured both acetabular and femoral morphology with the range of motion using 3D CT images (25). Sex differences were found not only in joint orientation, including anteversion and inclination of the acetabulum and femoral neck anteversion, but also in the shape around the joint, including the acetabular rim and the femoral neck. They reported the values of 25.2±9.8° for males and 20.3±9.9° for females. The Maruyama study had quantitatively similar results as our study, and they recorded a mean of 12.2±7.8° in males and 11.1±10.3° in females (26). Other studies analyzed the femoral AA values and came to similar conclusions (8,9,23). Our study showed greater anteversion in male samples in regard to their female counterparts but with the same range of values which could downplay the importance of mean values in conclusions regarding sex differences in morphometrics in general. Sex differences could play an important role in total hip arthroplasty, both in surgical techniques and prosthesis design. The lateral exposure facilities deepening of the socket without the danger of shortening the anterior wall (9,16,17). In anterior exposures, the acetabulum is viewed on an axis inclined anterolaterally, and the anterior rim of the socket tends not to be completely contained under the pubic ramus unless it is given an FAA is not advisable when using a small diameter head because if overdone dislocation could occur. Authors discussed the optimal orientation of the femoral component, and some propose angles between 15 and 30° for greater stability, while others choose 0° AAs (9,16,17). Lower AAs have a higher risk of THA failure as recorded by Redmond et al. (27). Lower femoral anteversion value and THA failures could be explained with males having abundant hip abductor musculature in regard to their female counterparts, resulting in a larger resultant force on the prosthesis socket. Although the hip abductor muscle strength seems to be the main factor resulting in a specific wear pattern, horizontal and vertical rotations play an important role in the Elson study, due to the fact that it is hard to imagine such a force in abduction movement larger than 30° (28). Our study contradicts such an explanation, seeing that the mean in our male samples was larger than in their female counterparts. Femoral AA correlates poorly with all of the proposed biomechanical factors. Although the angles around the proximal femur determine the two different coaptation forces that determine the static morphology of the joint space, no convincing correlation was found leading to the conclusion that FAA and AI together with the FHD and FBL although biomechanically linked do not affect each other morphology. We concluded that the FAA correlates negatively with the mediolateral and anteroposterior parameters which could play part in rotational problems during total knee arthroplasty (TKA) and total hip arthroplasty, seeing that the relationship between implant position and primary stability was highly dependent on the patient and the stem design used (29). The FAA is dependent on the approach and techniques used in THA together with spinopelvic balance, in hip replacements performed through a posterior approach and with mean cup inclination angle of 31°±6°, placing the lip of the elevated liner in the postero-inferior quadrant may impart more stability than in the postero-superior quadrant. Crane, Pitkow and Ireland described that, in decreased anteversion, there are a limited internal rotation and an increased external rotation of the hip with a toeing-out gait (30-32). Difficulties with the imaging of the FAA range from patient positioning to magnifying errors although many studies have described the acetabular side of the deformity, to our knowledge, littles is known about the three-dimensional (3D) head and neck offset differences of the femora (32,33). The 3D computed tomography (CT) measures for FAA are reliable within individual rater and between different raters. The 3D CT measueres of FAA can be a useful method for accurate diagnosis and follow-up of femoral anteversion (34,35). Besides alignment guides, rulers, and other tools, intraoperative fluoroscopy and computer-guided navigation allow the surgeon to intraoperatively analyze leg length and offset changes in relation to the FAA (36-40). Lim et al. confirmed that the femoral anteversion decreases after TKA probably due to the fact that references for FAA measurement the posterior parts of the femoral condyles are altered (29). However, the study suggests that patients with distal femoral deformity may demonstrate an overrunning rotation of the femur, a consideration which has not been widely acknowledged or addressed in the literature discussing TKA (29). Occult rotational deformity of the lower extremity that is not addressed in the surgical setting may adversely affect the outcome of TKA (29). They ascertained that distal femoral deformities lead to changes in the FAA which could be an expression of the forementioned negative correlations. Femoral anteversion is important in neuro-orthopaedics, particularly in cerebral palsy patients. Cerebral palsy gait with hip flexion, adduction, and inner rotation induces larger resultant forces and vertical forces on contact and reduces horizontal forces seemingly resulting in a larger AI and FAA, resulting in aberrant proximal femoral morphology (20). In normal growth and development, the AA is about 30± at birth and decreases to 15± by skeletal maturity. In children with cerebral palsy, the AA may not decrease and may even increase slightly during development (19). Most studies have found that the AA of children with cerebral palsy is 10–15± above the normal value. A large AA creates abnormal hip motion, increases the potential for dislocation of the hip, and may contribute to the development of osteoarthritis in the hip (19). Shefelbine and Carter developed an finite element method model that simulated progression in growth in normal and cerebral palsy affected hips (19). They showed that a decrease of −2° is expected in normal hips; however, a −1° increase is expected over 6 months in cerebral palsy affected hips under normal loading conditions. The FAA has a role in hip impingement syndromes, seeing that leverage of the femoral head against the acetabular rim may lead to posterior hip dislocation during sports activities in hips with femoroacetabular impingement deformity. Abnormal concavity of the femoral head and neck junction has been well described in association with posterior hip dislocation. However, acetabular morphology variations are not fully understood, and decreased acetabular AA and posterior acetabular coverage of the femoral head were associated with posterior dislocation of the hip in adolescents with sports-related injury even in the absence of a high-energy mechanism (41-43). Increased femoral anteversion can be associated with hip instability, redislocation after closed reduction, and subsequent early degenerative arthritis although in patients with unilateral DDH, AA was found to be significantly different between affected and unaffected sides. However, the difference had very limited or no clinical significance, as redislocation/subluxation was not influenced by AA values (44,45).

CONCLUSION

We measured femoral anteversion values in 100 human dry femora and compared those between the sexes. Although our findings show that, based on the mean values, male femora seem more anteverted with regard to their female counterparts. A statistically significant difference was ascertained between the male and female FAA values. Those findings should, however, be taken with caution, seeing that the range of values between male and female femora is identical even with the exclusion of retroverted femora. The difference in femoral AAs between male and female femora is significant with a $p<0.05$ which could play part in understanding hip pathologies regarding hip impingement, THA failures, and femoral endoprosthesis parts design as was shown through the narrative review of literature presented in the discussion section. Femoral AA correlated poorly with all of the implicated parameters, and negative correlation with both mediolateral and anteroposterior linear morphometric parameters of the distal femur could be used to explain rotational malalignment in THA with DFD, respectively. Femoral anteversion angle is widely recognized as a pathologic feature in cerebral palsy patients, cerebral palsy patients present with gait with hip flexion, adduction and inner rotation induces larger resultant forces and vertical forces on contact and reduces horizontal forces seemingly resulting in a larger AI and FAA, resulting in aberrant proximal femoral morphology. This study provides orthopedic surgeons and anthropologists with updated data and reviews on FAA values and sex differences specific to the region, which could be used in various studies as a reference and in clinical settings due to advancing methods and procedures including THA and cerebral palsy treatment.

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