Differences in CT Scan Measurements of Femoral Neck Shaft Angle and Acetabular Version Among Sex, Age, and Ethnicity from a Large Cadaveric Database

Bryce N. Clinger, MD[1]; Scott Plaster, MD[1]; River S. Fine, BS[2]; Justin R. Marshall, DO[3]; Dustin L. Richter, MD[1]

[1]Department of Orthopaedics & Rehabilitation, The University of New Mexico, Albuquerque, New Mexico
[2]School of Medicine, The University of New Mexico, Albuquerque, New Mexico
[3]Department of Radiology, The University of New Mexico School of Medicine, Albuquerque, New Mexico

Corresponding Author Bryce N. Clinger, MD. Department of Orthopaedics & Rehabilitation, 1 University of New Mexico, Albuquerque, MSC10 5600, NM 87131 (email: bnclinger@salud.unm.edu).

Funding The authors received no financial support for the research, authorship, or publication of this article.

Conflict of Interest The authors report no conflicts of interest.

Acknowledgements The authors would like to acknowledge Laurie Wells, PhD, for her statistical help.

ABSTRACT

Background: Management of proximal femur and acetabular pathologies, such as femoroacetabular impingement, hip osteoarthritis, or hip fractures, requires an understanding of the patient's anatomy for accurate diagnosis and treatment. Variability in femoral neck-shaft angle (FNA) and acetabular version (AV) has been shown, but little insight into differences between ages, ethnicities, and sexes has been evaluated.

Methods: Two hundred and fifty cadaveric specimens from the New Mexico Decedent Image Database were evenly divided by sex and among five ethnic groups (Asian American, Black/African American, Hispanic, Native American, White). Using multiplanar reconstruction, thin-cut computed tomography scans were reviewed by three independent observers. Intra-class correlation coefficient (ICC) was calculated, and analysis of variance and a Tukey multiple comparison test were used to evaluate differences.

Results: The average age was 49.4 years (range 19 to 103). Average FNA and AV were 130.1° (115.7° to 144.7°) and 20.2° (8.2° to 36.6°), respectively. FNA ICC was 0.61 (good), and acetabular version ICC was 0.88 (excellent). No significant differences among groups were seen with FNA or AV for ethnicity (P=0.651, P=0.944) or age (P=0.37, P=0.94). There was no significant difference among sex with FNA (P=0.89); however, there was a significant difference with AV (P<0.01) with the Tukey multiple comparison test showing that males had 2.6° less acetabular anteversion than females.

Conclusions: The authors found a significant difference in AV for sex only, with males having 2.6° less AV than females, and no difference in FNA seen with sex. When looking at ethnicity and age, no differences in FNA or AV were observed. AV and FNA are similar despite age, sex, or ethnicity.

Keywords: Acetabulum; Hip Joint; Femur Neck; Anatomy

INTRODUCTION

Femoral neck-shaft angle (FNA) and acetabular version (AV) are important anatomic diagnostic references used clinically in orthopaedics. FNA has been defined as the intersection angle between the proximal femoral shaft and the femoral neck.[1,2] Measurement of FNA is influenced by pelvic rotation and femoral version and can therefore be difficult to accurately measure on plain radiographs.[1] AV is the orientation of the acetabulum measured by a line that connects the anterior acetabular margin with the posterior acetabular margin and a perpendicular reference line either through the center of the femoral head, the posterior acetabular wall, or the posterior aspect of the ischial bone.[3-6] Acetabular tilt must be taken into consideration for accurate measurement of AV.[7]

Looking at the clinical implications of variations of FNA and AV, Gnudi et al[8] found that increased femoral neck-shaft angle was associated with a greater risk for proximal femur fractures. Another study by Fearon et al[9] showed that a decreased neck-shaft angle increased the risk for greater trochanteric pain in women, and Sun et al[10] found that lower FNA were associated with both partial- and full-thickness gluteus medius tears. Acetabular anteversion is associated with an increased risk for postoperative dislocation following total hip arthroplasty, developmental dysplasia, and gluteal tendinopathy.[11,12]

Both FNA and AV have been implicated in femoroacetabular impingement (FAI) and the subsequent development of osteoarthritis (OA) due to the repetitive contact of abnormal morphology between the proximal femur and acetabulum, causing chondral and labral damage.[13] Acetabular retroversion has been shown as a significant risk factor for pincer-type FAI in women due to the increased coverage of the femoral head by the anterior acetabulum.[14-17] FAI is becoming more accepted as a cause of hip pain in young patients and should be evaluated for those with hip pain.[18,19] Assessment of FNA and AV is an important anatomical consideration for diagnosis, treatment, and preoperative planning in various hip pathologies.

Despite the literature showing that hip morphological differences affect pain and function, little information is available regarding variations in FNA and AV among patients of different ethnicities.[8,9,11,12] Among ethnicities, most literature on the differences in hip anatomy concerns hip dysplasia and not directly AV or FNA measurements.[20-22] By understanding potential anatomical differences in groups of patients, surgeons can improve diagnosis, treatment, and patient outcomes. In this study, the authors hypothesized that significant differences in FNA and AV do exist between ethnicities, age, and sex.

METHODS

After obtaining institutional review board exemption from this institution, a retrospective review of the New Mexico Decedent Image Database (NMDID) was undertaken for this study population. The NMDID is a public database of over 15,000 individuals with full-body high-resolution computed tomography (CT) scans of deceased individuals prior to undergoing an autopsy through the New Mexico Office of the Medical Investigator and The University of New Mexico.[23] Individuals were identified by age, sex, and ethnicity with corresponding CT scans capable of 3-dimensional reconstruction.

Two hundred and fifty individuals evenly divided by sex and among five ethnic groups (African American/Black, American Asian, Hispanic, Native American, and White) represent the study population. Inclusion criteria were > 18 years old, no total or partial hip arthroplasty, retained implants, or obvious acetabular/pelvic fractures. Exclusion criteria were < 18 years old, obvious fractures to the acetabulum or proximal femur, retained implants, and poor CT image quality with the inability to perform multiplanar reconstruction (MPR) for measurements. As a result of the inclusion/exclusion criteria, only 25 Asian-American females were able to be included in the study. To have an even distribution of this study population, 25 males and females from each ethnic group were set as this study size for a total of 250 specimens. All specimens had thin cut (0.5 mm) and high-resolution CT scans with MPR of their lower extremities to ensure accurate measurements.

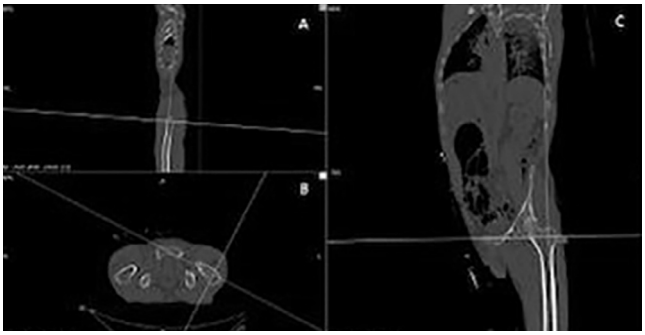

Figure 1. *Multiplanar Reconstruction Software showing thin-cut computed tomography scans for femoral neck-shaft angle measurement. A) Longitudinal axis of femur identified on sagittal imaging. B) Axial plane axis parallel through the femoral neck to ensure true anterior-posterior view of the femoral neck on coronal imaging. C) Coronal imaging with measurement of femoral neck through midline of neck and then in line with longitudinal axis of the femoral shaft.*

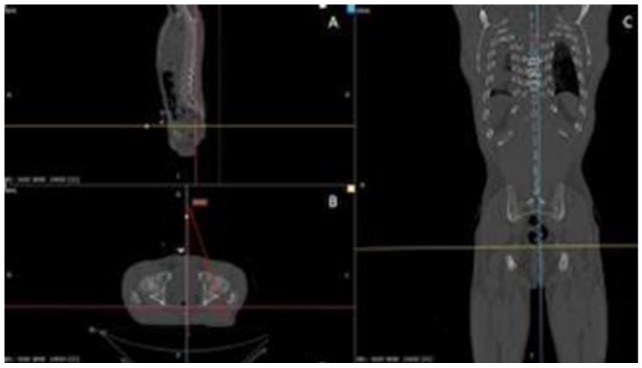

Figure 2. *Multiplanar Reconstruction Software showing thin-cut computed tomography scans for acetabular version measurement. A) Longitudinal axis set parallel to hip joint on sagittal imaging. B) Axial imaging, pink line at most posterior point of bilateral ischial spines, acetabular version measurement from most prominent anterior and posterior acetabular anatomy referenced off the transverse (blue line) of the pelvis. C) Coronal imaging with longitudinal axis parallel to hip joint.*

Three reviewers (two senior orthopaedic residents, BC & SP; and one senior radiology residen,t JM) independently measured FNA and AV. All measured data were entered and stored in the REDCap database tool (Research Electronic Data Capture, Vanderbilt University) while being blinded to the other reviewers. An MPR software, RadiAnt DICOM Viewer (Version 2021.1; Medixant), was used by all reviewers for measurements.

FNA was measured after ensuring the longitudinal axis was in line with the femoral shaft on coronal and sagittal cuts (Figure 1A). The axial plane axis was made parallel through the femoral neck to give a true anterior posterior view of the neck on coronal CT imaging (Figure 1B). The FNA was then measured parallel through the midline of the neck and then through the midline of the femoral shaft according to the longitudinal axis of the femoral shaft (Figure 1C).

AV was measured with coronal and sagittal imaging set to ensure the longitudinal axis was parallel to the joint (Figures 2A and 2C). On axial imaging, the reference point was the transverse axis at the most posterior point of the bilateral ischial spines, to adjust for rotation. AV was then measured from posterior to anterior of the most prominent aspects of the acetabulum margin. An angle was then drawn to parallel the transverse line of that set from the ischial spine line to determine the AV (Figure 2B).

Statistics were calculated using statistical software (R Studio v1.4.1717). Intra-class correlation coefficient (ICC) was calculated for inter-observer reliability. ICC value of < 0.40 was considered poor, 0.40 to 0.59 was considered fair, 0.60 to 0.74 was considered good, and 0.75 to 1 was considered excellent.[24] The three reviewers agreed upon using inter-observer reliability. Statistical significance was set at $P < 0.05$.

Analysis of Variance (ANOVA) testing was used to find any statistically significant difference in FNA and AV among ethnicity, age, and sex. If statistically significant, the Tukey multiple comparison test was used to identify the difference.

RESULTS

Average FNA was 130.1° (115.7° to 144.7°). Average AV was 20.2° of anteversion (8.2° to 36.6°). FNA ICC was 0.61 (Good) and AV ICC was 0.88 (Excellent). No significant difference was found among ethnic groups with FNA (P=0.65) or AV (P=0.94) (Table 1). No significant difference was found among sex with FNA (P=0.89) (Table 2). However, a statistically significant difference was found with AV ($P < 0.01$). The Tukey multiple comparison test showed that male patients have 2.6° less anteversion than female patients. No significant difference was found among age groups with FNA (P=0.37) or AV (P=0.94) (Table 3).

Table 1. Mean and SD of FNA and AV among ethnicities.[a]

Ethnicity (n=250)	FNA (º) Mean	SD	AV (º) Mean	SD
Asian (n=50)	129.89	5.70	19.95	5.37
Black (African American) (n=50)	129.93	4.37	20.09	5.26
Hispanic (n=50)	130.83	4.64	19.96	5.63
Native American (n=50)	129.43	4.63	19.96	4.89
White (n=50)	130.34	4.31	20.66	4.37

[a]SD: Standard Deviation; FNA: Femoral Neck Shaft Angle; AV: Acetabular Version

Table 2. Mean and SD of FNA and AV among sex.[a]

Sex (n=250)	FNA (º) Mean	SD	AV (º) Mean	SD
Female (n=125)	130.05	4.63	21.49	5.27
Male (n=125)	130.13	4.87	18.94	4.57

[a]SD: Standard Deviation; FNA: Femoral Neck Shaft Angle; AV: Acetabular Version

Table 3. Mean and SD of FNA and AV among age groups.[a]

Age (n=250)	FNA (º) Mean	SD	AV (º) Mean	SD
<30 (n=38)	131.86	4.72	18.57	4.29
31-40 (n=47)	130.47	4.94	18.72	4.49
41-50 (n=36)	129.62	4.42	19.60	3.99
51-60 (n=56)	129.65	4.26	20.99	4.63
61-70 (n=41)	129.41	4.54	20.87	5.93
71-80 (n=19)	130.21	5.53	22.27	6.67
81-90 (n=9)	128.88	5.87	22.81	4.49
91-103 (n=4)	128.23	6.44	26.05	7.85

[a]SD: Standard Deviation; FNA: Femoral Neck Shaft Angle; AV: Acetabular Version

DISCUSSION

Studies have shown variability in the anatomy between patients of different sex and age.[20-22,25-28] However, very little research has been done regarding variability in hip anatomy of patients from various ethnicities. Thus, the authors chose to investigate the possible variations in hip anatomy, including FNA and AV, in patients of diverse ethnic backgrounds to provide insight into potential risk factors for injuries, diagnosis, and treatment of hip pathology. This study found that there was no significant difference in FNA or AV in patients of different age or ethnicity. Moreover, no significant difference in FNA was found among sex. However, the authors did find a statistically significant difference in AV ($P < 0.01$) among patients of different sex, with male patients having 2.6° less acetabular anteversion than female patients.

This study has several limitations. First, this is a retrospective review of cadavers with limited demographic data and unknown history of hip pain or prior hip trauma. Second, although inter-rater reliability was determined to be good to excellent, potential measurement error exists. Three reviewers independently reviewed the images with the same MRP viewing software. However, it is hard to measure with precise accuracy the correct angle and referencing points. No intra-observer reliability was completed, which would have helped the reviewers determine if their measurements were reproducible.

Lastly, despite a large database, this sample size was limited to 250 specimens due to the fact that only 25 female Asian Americans were able to be included in the study. To ensure an equal distribution of patient population, the authors wanted the same number of specimens from each population group, which in this case was limited to 250 total specimens. This could lead to some of the nonsignificant findings being a result of a type II error. Despite these limitations, the authors believe

that these measurements and findings are accurate. This study was the first to explore anatomic differences between AV and FNA among five different ethnicities, including that of Native Americans. Measurements of FNA and AV were similar among patients of different ethnicities and ages in this study, which is similar to other reported literature. Miyasaka et al[27] reported similar findings showing no significant differences in AV between younger and older females. These results are in contrast to other studies that have found a statistically significant difference in hip morphology among patients of different ages and ethnicities.[20] Gilligan et al[21] found that the average FNA trended downward with age. When comparing ethnicity, Lavy et al[22] found that Japanese patients had more dysplastic hips when compared to British patients, who were more dysplastic than Malawian hips. However, they also reported that these differences in hip morphology could be attributed to cultural differences in which babies are carried.[22] It should also be noted that hip morphology, which used to be considered pathologic, is now being considered normal due to more precise diagnostic measurements.[29] This presents the possibility that hip anatomy does not differ significantly among patients of different age and ethnicity. Instead, imaging and diagnostic techniques have improved to rule out true pathology versus normal anatomical differences.

The observed difference in AV seen in this study for sex is in line with previous studies that have suggested females have more anteversion than males as seen on CT scans.[27] Similarly, Klasan et al[30] found that females had a higher average anteversion than males. Atkinson et al[25] described similar findings, reporting that females had an AV of 23° compared to their male counterparts who had an AV of 18°. They also reported no significant difference in FNA between females and males. This is further supported by Gilligan et al[21] who reported that males and females have a similar mean FNA (125.2°) in a cohort of 3,348 patients. However, conflicting results has been reported in regard to FNA between males and females. Traina et al[28] reported that females had decreased FNA when compared to males.[28] FNA was reported to be decreased in males when compared to females, suggesting possible inconclusive findings.[26] Although statistically significant, the 2.6° difference in AV seen in this study is unlikely to be clinically significant.

Future studies may investigate the clinical significance of these findings regarding the 2.6° difference of AV in males compared to females and if it plays a significant role in the development of OA, FAI, or other hip pathology. Among ethnicities, this study was the first to explore possible differences in five ethnic groups, showing no difference in FNA or AV, as also seen for age. Understanding anatomic differences among groups is helpful, but more importantly, the anatomic similarities among a large cohort of ethnically diverse patients can aid the surgeon in providing the most complete care for their patients.

REFERENCES

1. Boese CK, Dargel J, Oppermann J, et al. The femoral neck-shaft angle on plain radiographs: a systematic review. Skeletal Radiol. 2016;45(1):19-28. doi: 10.1007/s00256-015-2236-z.
2. Jiang N, Peng L, Al-Qwbani M, et al. Femoral version, neck-shaft angle, and acetabular anteversion in Chinese Han population: a retrospective analysis of 466 healthy adults. Medicine (Baltimore). 2015;94(21):e891. doi: 10.1097 MD.0000000000000891.
3. Hingsammer AM, Bixby S, Zurakowski D, et al. How do acetabular version and femoral head coverage change with skeletal maturity? Clin Orthop Relat Res. 2015;473(4):1224-1233. doi: 10.1007/s11999-014-4014-y.
4. Lembeck B, Mueller O, Reize P, et al. Pelvic tilt makes acetabular cup navigation inaccurate. Acta Orthop. 2005;76(4):517-523. doi: 10.1080/17453670510041501.
5. Mast JW, Brunner RL, Zebrack J. Recognizing acetabular version in the radiographic presentation of hip dysplasia. Clin Orthop Relat Res. 2004;(418):48-53. doi: 10.1097/00003086-200401000-00009.
6. van Bosse H, Wedge JH, Babyn P. How are dysplastic hips different: a three-dimensional CT study. Clin Orthop Relat Res. 2015;473(5):1712-1723. doi: 10.1007/s11999- 014-4103-y.
7. Fujii M, Nakashima Y, Sato T, et al. Acetabular tilt correlates with acetabular version and coverage in hip dysplasia. Clin Orthop Relat Res. 2012;470(10):2827-2835. doi: 10.1007/s11999-012 2370-z.
8. Gnudi S, Ripamonti C, Lisi L, et al. Proximal femur geometry to detect and distinguish femoral neck fractures from trochanteric fractures in postmenopausal women. Osteoporos Int. 2002;13(1):69-73. doi: 10.1007/s198-002-8340-2.
9. Fearon A, Stephens S, Cook J, et al. The relationship of femoral neck shaft angle and adiposity to greater trochanteric pain syndrome in women. A case control morphology and anthropometric study. Br J Sports Med. 2012;46(12):888-892. doi: 10.1136/bjsports-2011-090744.
10. Sun H, Huang HJ, Mamtimin M, et al. Hip gluteus medius tears are associated with lower femoral neck-shaft angles and higher acetabular center-edge angles. Arthroscopy. 2022;38(5):1496-1505. doi: 10.1016/j.arthro.2021.10.006.
11. Maruyama M, Feinberg JR, Capello WN, et al. The Frank Stinchfield Award: morphologic features of the acetabulum and femur: anteversion angle and implant positioning. Clin Orthop Relat Res. 2001;(393):52-65.
12. Yun HH, Yoon JR, Yu JJ, et al. Navigated acetabular cup fixation for acetabular deformity or revision total hip arthroplasty. Hip Pelvis. 2014;26(3):150-156. doi: 10.5371/hp.2014.26.3.150.
13. Gollwitzer H, Suren C, Strüwind C, et al. The natural alpha angle of the femoral head-neck junction: a

cross-sectional CT study in 1312 femurs. Bone Joint J. 2018;100-B(5):570-578. doi: 10.1302/0301-620X.100B5.BJJ-2017-0249.R3.
14. Banks KP, Grayson DE. Acetabular retroversion as a rare cause of chronic hip pain: recognition of the figure-eight sign. Skeletal Radiol. 2007;36 Suppl 1:S108-S111. doi: 10.1007/s00256-006-0150-0.
15. Bouma HW, Hogervorst T, Audenaert E, et al. Can combining femoral and acetabular morphology parameters improve the characterization of femoroacetabular impingement? Clin Orthop Relat Res. 2015;473(4):1396-1403. doi: 10.1007/s11999-014-4037-4.
16. Kim CH, Moon JK, Yoon JY, et al. Arthroscopy versus nonoperative treatment of symptomatic femoroacetabular impingement syndrome: a systematic review and meta-analysis. Medicine (Baltimore). 2020;99(49):e23247. doi: 10.1097 MD.0000000000023247. Erratum in: Medicine (Baltimore). 2021;100(8):e24964.
17. Reynolds D, Lucas J, Klaue K. Retroversion of the acetabulum. A cause of hip pain. J Bone Joint Surg Br. 1999;81(2):281-288. doi: 10.1302/0301-620x.81b2.8291.
18. Tannenbaum E, Kopydlowski N, Smith M, et al. Gender and racial differences in focal and global acetabular version. J Arthroplasty. 2014;29(2):373-376. doi: 10.1016/j.arth.2013.05.015.
19. Tannenbaum EP, Zhang P, Maratt JD, et al. A computed tomography study of gender differences in acetabular version and morphology: implications for femoroacetabular impingement. Arthroscopy. 2015;31(7):1247-1254. doi: 10.1016/j.arthro.2015.02.007.
20. Edwards K, Leyland KM, Sanchez-Santos MT, et al. Differences between race and sex in measures of hip morphology: a population-based comparative study. Osteoarthritis Cartilage. 2020;28(2):189-200. doi: 10.1016/j.joca.2019.10.014.
21. Gilligan I, Chandraphak S, Mahakkanukrauh P. Femoral neck-shaft angle in humans: variation relating to climate, clothing, lifestyle, sex, age and side. J Anat. 2013;223(2):133-151. doi: 10.1111/joa.12073.
22. Lavy CB, Msamati BC, Igbigbi PS. Racial and gender variations in adult hip morphology. Int Orthop. 2003;27(6):331-333. doi: 10.1007/s00264-003-0507-0.
23. Daneshvari Berry S, Kroth PJ, Edgar HJH, et al. Developing the minimum dataset for the New Mexico decedent image database. Appl Clin Inform. 2021;12(3):518-527. doi: 10.1055/s-0041-1730999.
24. Cicchetti DV. The precision of reliability and validity estimates re-visited: distinguishing between clinical and statistical significance of sample size requirements. J Clin Exp Neuropsychol. 2001;23(5):695-700. doi: 10.1076/jcen.23.5.695.1249.
25. Atkinson HD, Johal KS, Willis-Owen C, et al. Differences in hip morphology between the sexes in patients undergoing hip resurfacing. J Orthop Surg Res. 2010;5:76. doi: 10.1186/1749-799X-5-76.
26. Fischer CS, Kühn JP, Völzke H, et al. The neck-shaft angle: an update on reference values and associated factors. Acta Orthop. 2020;91(1):53-57. doi: 10.1080/17453674.2019.1690873.
27. Miyasaka D, Sakai Y, Ibuchi S, et al. Sex- and age-specific differences in femoral head coverage and acetabular morphology among healthy subjects-derivation of normal ranges and thresholds for abnormality. Skeletal Radiol. 2017;46(4):523-531. doi: 10.1007/s00256-017-2583-z.
28. Traina F, De Clerico M, Biondi F, et al. Sex differences in hip morphology: is stem modularity effective for total hip replacement? J Bone Joint Surg Am. 2009;91 Suppl 6:121-128. doi: 10.2106/JBJS.I.00533.
29. Buller LT, Rosneck J, Monaco FM, et al. Relationship between proximal femoral and acetabular alignment in normal hip joints using 3-dimensional computed tomography. Am J Sports Med. 2012;40(2):367-375. doi: 10.1177/0363546511424390.
30. Klasan A, Neri T, Sommer C, et al. Analysis of acetabular version: retroversion prevalence, age, side and gender correlations. J Orthop Translat. 2019;18:7-12. doi: 10.1016/j.jot.2019.01.003.