ORIGINAL ARTICLE

Correlation between Femoral Neck Version, Sagittal Femoral Bowing Angle and Sagittal Offset of the Femoral Head from the Distal Femur Axis in an Osteological Collection

Dedi Ho[1], Raymond W Liu[2], Philip K McClure[3]

Received on: 16 March 2022; *Accepted on:* 03 April 2023; *Published on:* 31 May 2023

Abstract

Aim: Radiographic analysis of lower limb alignment is crucial for the planning and evaluation of deformity correction. Assessment in the sagittal plane is often overlooked compared with the coronal plane for a variety of reasons. We aimed to investigate the relationship between the femoral head in the sagittal plane and femoral neck version in the axial plane, and how sagittal femoral bowing angle (sFBA) may contribute.

Materials and methods: Twenty-five each of high (1–2 standard deviations above mean), normal (2.5° below to 2.5° above the mean), and low (1–2 standard deviations below the mean) version femurs were randomly selected from an osteological collection database, photographed and measured for sFBA and sagittal offset of femoral head from the distal femur axis. Lines were drawn within the proximal and distal quartiles of the shaft to create sFBA. The offset of the distal quartile line and the femoral head was also measured. High intra- and inter-observer correlations were established. The relationship between parameters was assessed using the Pearson coefficient (*r*).

Results: Sagittal offset of the femoral head from the distal femur axis was found to be highly correlated with sFBA ($r = 0.78$), and only mildly with femoral neck version ($r = 0.52$). Sagittal femoral bowing angle and femoral neck version share no relationship ($r = 0.05$).

Conclusions: Neither the sFBA nor sagittal femoral head offset is strongly associated with femoral neck version.

Clinical significance: Our data reinforce the need for long leg lateral films to include the femoral head in sagittal deformity analysis, as imaging limited to the knee will not account for the effect of bowing on femoral head position.

Keywords: Femoral anteversion, Osteological study, Sagittal femoral bowing angle.

Strategies in Trauma and Limb Reconstruction (2023): 10.5005/jp-journals-10080-1577

Introduction

Radiographic analysis of lower limb alignment is a crucial part of deformity correction planning.[1] Historically, the focus of deformity planning has been in the coronal plane, perhaps in part because it is more readily apparent. Literature is mixed regarding sagittal deformity and contribution to arthritis. For example, deformity in the coronal plane was associated with knee degenerative disease in a cadaveric tibial malunion collection while deformity in the sagittal plane was not.[2] In contrast, several studies have demonstrated sagittal deformity as a risk factor for degenerative disease after fracture.[3–5] One study noted that sagittal deformity was more strongly associated with arthritis than coronal, though higher deformity angles were present in the sagittal plane potentially skewing results.[4] The sagittal plane is important in many clinical circumstances and can be easily overlooked in deformity correction planning. To a large degree, this is due to the deformity being in the plane of motion of adjacent joints. Deformity is often readily apparent on long leg lateral films when obtained properly, though not all institutions are well equipped to obtain reliable imaging. This can, in part, be attributed to the challenges involved in capturing sagittal plane radiographs reliably.[6–8] Dynamic factors such as patient position need to be taken into consideration.[1,9] For example, assessment of the sagittal mechanical axis (sMA) should be done on an image where the knee is in maximal extension, this often must be done in the supine position to allow relaxation of the hamstring muscles.

[1]Case Western Reserve University School of Medicine, Cleveland, Ohio, United States

[2]Pediatric Orthopedics, Rainbow Babies and Children's Hospital, Case Western Reserve University, Cleveland, Ohio, United States

[3]Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Crownsville, Maryland, United States

Corresponding Author: Dedi Ho, Case Western Reserve University School of Medicine, Cleveland, Ohio, United States, Phone: +015172929289, e-mail: dxh480@case.edu

How to cite this article: Ho D, Liu RW, McClure PK. Correlation between Femoral Neck Version, Sagittal Femoral Bowing Angle and Sagittal Offset of the Femoral Head from the Distal Femur Axis in an Osteological Collection. Strategies Trauma Limb Reconstr 2023;18(1):12–15.

Source of support: Nil

Conflict of interest: None

Of recent interest are angles between sMA and various distal femur axes, as well as predictors of these angles.[10,11] Chung et al.[12] found sagittal bowing to be a strong predictor of differences between sMAs and distal femoral axes. Less attention has been paid to the position of the femoral head in the sagittal plane, especially in relation to axial plane measurements such as femoral neck version. Theoretically, changes in femoral version should alter the superior–inferior position of the femoral head when viewed axially or laterally. Consistent with this theory, Müller et al.[13] found an association between sagittal stem alignment, resulting femoral head centre, and functional anteversion in a study of total hip arthroplasty prosthetics. The purpose of this study was to evaluate whether sagittal bowing of the femoral shaft is correlated to anteversion and the appearance of the femoral head in the lateral view. Our hypothesis is that femoral head position on the sagittal plane and anteversion are related to the magnitude of the femoral bow, with increased anteversion present in healthy individuals with an increased sagittal bow. To avoid issues based on limb positioning, we designed an osteological study to assess the correlation between femoral neck version, sagittal femoral bowing angle (sFBA) and sagittal offset of the femoral head from the distal femur axis using femora with known high, normal and low version values.

Materials and Methods

For our investigation, we identified 75 femurs of varying sex and race from the Hamann-Todd Human Osteologic Collection housed in the Cleveland Museum of Natural History (Cleveland, OH). Freely accessible for legitimate research, the collection comprises more than 3,000 human skeletons collected between 1912 and 1938. Twenty-five each of high, normal and low version femurs were randomly selected from our existing database of version values. High version femurs ranged between one and two standard deviations above the average version degree (24.4–36.3°). Normal version femurs ranged from 2.5° below to 2.5° above the average (9.9–14.9°). Low version femurs ranged between one and two standard deviations below the average (–11.4 to 0.5°).

Measurement Technique

Each specimen was placed on a flat surface, with markers for the positions of the intercondylar notch and orientation of the anatomic axis, resting on the posterior aspects of the distal femoral condyles and the posterior aspect of the greater trochanter before axial and lateral view digital photographs were taken. The digital camera was fixed in one position and remained unchanged for each specimen. Femoral neck version was measured using the Kingsley Olmsted method.[14] On axial view photographs, a line along the femoral neck was drawn. The angle between this line and the flat surface upon which the femur rests (representing the posterior condylar line) was recorded as the version.

Sagittal femoral bowing angle was measured using Yau's method, which has high intra- and interobserver reliability.[15,16] On lateral view photographs, the diaphysis of the femur was divided into quartiles and the midpoint of the medullary canal was marked at each division line (Fig. 1). The transition from metaphysis to diaphysis was based on measuring one femoral condyle antero-posterior width from the joint line. The distal quartile axis and proximal quartile axis were marked and the angle between the two axes was recorded as the sFBA.

Sagittal offset of the femoral head from the distal femur axis was obtained by drawing an orthogonal line from the distal quartile axis to the centre of the femoral head (Fig. 1). A calibration ruler was included in all images with the ruler and bone equidistant to the camera.

Statistics

Each measurement was obtained twice on separate occasions by a single reviewer. Twenty random femurs were measured a third time by a second reviewer. Assessed using SPSS 25.0 (IBM Corp., Armonk, NY), both intra-observer [intraclass correlation coefficient (ICC) = 0.987 (95% confidence interval, CI: 0.971–0.994)] and inter-observer correlation [ICC = 0.991 (95% CI: 0.978-0.997)] was found to be high for sFBA measurements. Intra-observer [ICC = 0.997 (95% CI: 0.993–0.999)] and inter-observer correlation [ICC = 0.996 (95% CI = 0.989–0.998)] for sagittal offset of femoral head from the distal femur axis measurements was high as well. The relationship between version, sFBA and sagittal offset was assessed using the Pearson coefficient (*r*).

Fig. 1: A lateral view of the femur is used to determine sFBA and sagittal offset of the femoral head from the distal femur axis (L). First, the position of the distal metaphysis–diaphysis transition line (shown in green) is determined to be one antero-posterior width of the femoral condyle away from the joint line (shown in red). Next, the position of the proximal metaphysis-diaphysis transition line (shown in magenta) is determined to be just inferior to the trochanter. The transition lines are then used to find the 25th and 75th quartile lines (shown in blue). Distal and proximal femur axes (shown as white continuous lines) are drawn to intersect midpoints of each quartile line. Sagittal femoral bowing angle is the angle between these two axes. Lastly, the sagittal offset of the femoral head from the distal femur axis (L) is marked as the orthogonal line between the distal femur axis and centre of the femoral head (shown in orange). The white dashed line is the horizontal plane in which all quartile lines are perpendicular to.

Results

High version femurs ranged from 24.4 to 36.3°. Normal version femurs ranged from 9.9 to 14.9°. Low version femurs ranged from –11.4 to 0.5°.

For each version group, we recorded the average femoral neck version, sFBA and sagittal offset of the femoral head from the distal femur axis, as well as interquartile range (Table 1).

A Pearson correlation coefficient (*r*) of 0.78 was found between sFBA and sagittal offset (Fig. 2). Correlation between sagittal offset and version was lower ($r = 0.52$), while correlation between sFBA and version ($r = 0.05$) was minimal (Figs 3 and 4).

Conclusion

Assessment of sagittal plane alignment is crucial for the planning and evaluation of lower extremity deformity correction. Sagittal plane position of the femoral head is of especial importance since its centre is used as a landmark for determining various reference angles and lines such as sagittal plane mechanical axis. We evaluated femoral head position by measuring sagittal offset from the distal femur axis. Our data demonstrated a strong relationship between sagittal offset of the femoral head and sagittal bow of the femur, with a correlation coefficient of 0.78. Femoral neck version was not related to sagittal bow and played a minimal role in femoral neck offset. On the contrary, sFBA was not related to femoral neck version, while sagittal offset was only mildly related to version. Some difference in sagittal offset with version is expected, based

Table 1: Average femoral neck version, sagittal femoral bowing angle and sagittal offset of the femoral head from the distal femur axis for high, normal and low version femora

	Femoral neck version (IQR)	*Sagittal femoral bowing angle (IQR)*	*Sagittal offset (IQR)*
High version	27.5 (25.0–29.5)	11.4 (9.6–13.8)	15.3 (6.3–26.7)
Normal version	12.4 (11.2–13.8)	11.7 (9.4–13.2)	24.2 (17.2–31.8)
Low version	−6.1 (−8.0 to −4.4)	12.0 (10.1–13.5)	29.6 (24.25–33.2)

IQR, interquartile range

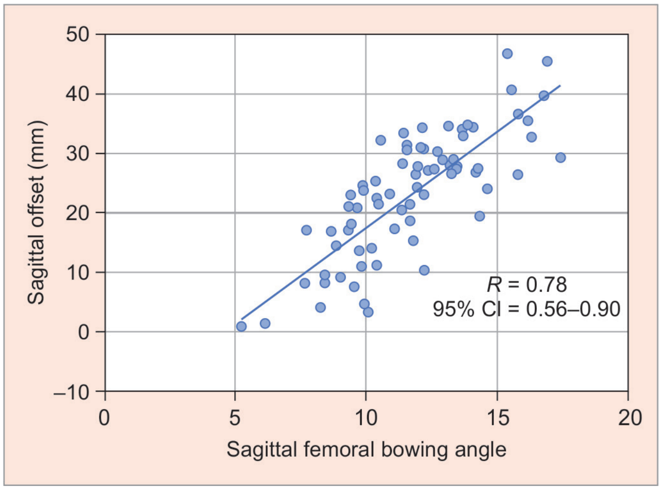


Fig. 2: Graph of sagittal femoral bowing angle vs sagittal offset ($R = 0.78$)

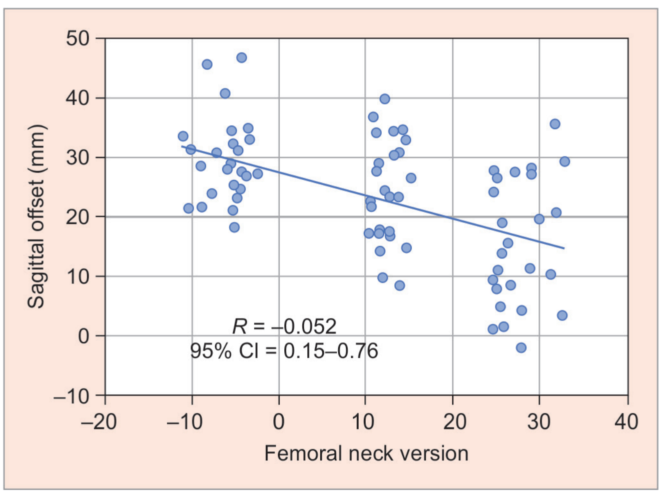


Fig. 3: Graph of femoral neck version vs sagittal offset of the femoral head from the distal femur axis ($R = -0.52$)

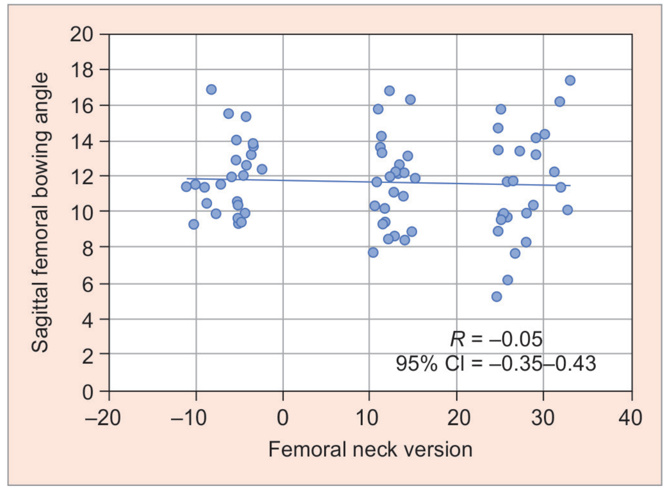
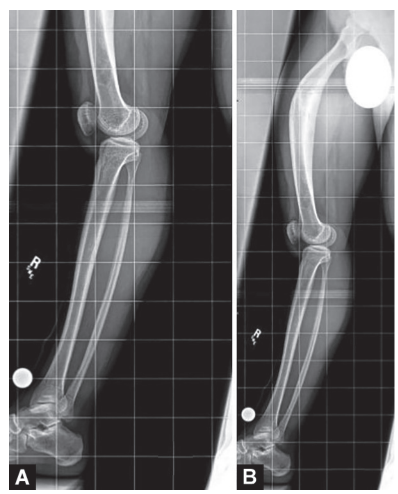


Fig. 4: Graph of femoral neck version vs sagittal femoral bowing angle ($R = -0.05$)



Figs 5A and B: Radiograph of flexion deformity in the femoral shaft (B) with compensatory hyperextension deformity around the knee (A)

on the geometrical relationships increased femoral anteversion should decrease sagittal offset which was the relationship found in this study.

Overall, these findings support no relationship between femoral bowing and femoral version, and suggest that the sagittal and axial planes remain separate in terms of sagittal femoral head offset. This strengthens the concept of using the femoral head in sagittal plane analysis even in the presence of rotational deformity. In addition, these findings reinforce the importance of full-length sagittal plane radiographs in deformity planning to fully assess the sagittal plane mechanical axis. The use of a lateral knee radiograph to assess anatomical posterior distal femoral angle (aPDFA), does not account for the influence of the femoral bow, and the effect of the femoral bow can vary substantially as demonstrated by this data set. An extreme example would be a flexion deformity in the femoral shaft with compensatory hyperextension deformity around the knee (Fig. 5). The knee radiograph including only the distal femur is not adequate for deformity planning in this case. Referencing the distal femur should not stand as a substitute for complete evaluation of the long axis of the femur, as the anatomic axis of the distal femur was not predictive of the position of the femoral head. In general, an ideal full length lateral view should span from the femoral head to the talus, with the knee in maximal extension, and the femoral condyles overlapped as much as possible.

The correlation between sagittal offset and sFBA is consistent with conclusions made by Chung et al.[12] in a 2009 radiographic study. These authors found that for each degree of anterior bowing, the deviation between mechanical and distal axes increased by approximately half a degree. Our study provides additional data regarding the sagittal offset between the distal axis and the femoral head.

A significant limitation of this study identified is the generalizability of our osteological findings. Our recommendations for radiography protocols are based on measurements obtained from digital photographs. However, we were careful to position each specimen and obtain each measurement with consistency. Contributing to the issue of generalizability is our limited sample size of 75 femurs. To circumvent this, we deliberately selected specimens that would cover a range of femoral version degrees and more importantly, had equal representation in high, normal and low version groups.

Clinical Significance

In summary, sFBA and the sagittal offset of the femoral head from the distal femur axis are related while femoral neck version is not strongly related to either. This allows for sagittal plane planning without concerns related to axial plane rotational deformity. Owing to the variability in femoral bow and anteversion without a clear predictive relationship, drawing the PDFA based on distal anatomic structures alone may not be reliable compared with using the mechanical axis of the limb, and could lead to errors in planning. Thus, radiographs in the sagittal plane should encompass the full femur, as the distal anatomic axis cannot be used to predict femoral head position.

Orcid

Raymond W Liu https://orcid.org/0000-0003-3041-8312
Philip K McClure https://orcid.org/0000-0003-4379-7622

References

1. Paley D. Sagittal plane deformities. Princ Deform Cor 2005;6:155–174. DOI:10.1007/978-3-642-59373-4_6.
2. Weinberg DS, Park PJ, Liu RW. Association between tibial malunion deformity parameters and degenerative hip and knee disease. J Orthop Trauma 2016;30(9):510–515. DOI: 10.1097/BOT.0000000000000603.
3. Agneskirchner JD, Hurschler C, Stukenborg-Colsman C, et al. Effect of high tibial flexion osteotomy on cartilage pressure and joint kinematics: a biomechanical study in human cadaveric knees. Winner of the AGA-DonJoy Award 2004. Arch Orthop Trauma Surg 2004;124(9):575–584. DOI: 10.1007/s00402-004-0728-8.
4. Palmu SA, Lohman M, Paukku RT, et al. Childhood femoral fracture can lead to premature knee-joint arthritis. 21-year follow-up results: A retrospective study. Acta Orthop 2013;84(1):71–75. DOI: 10.3109/17453674.2013.765621.
5. Klek M, Dhawan A. The role of high tibial osteotomy in ACL reconstruction in knees with coronal and sagittal plane deformity. Curr Rev Musculoskelet Med 2019;12(4):466–471. DOI: 10.1007/s12178-019-09589-9.
6. Kremen TJ Jr, Haggerty E, Chahla J, et al. Comparative analysis of sagittal-plane radiographic landmarks used to identify the femoral attachments of lateral knee structures. Arthroscopy 2020;36(11):2888–2896. DOI: 10.1016/j.arthro.2020.07.006.
7. Ziegler CG, Fulkerson JP, Edgar C. Radiographic reference points are inaccurate with and without a true lateral radiograph: The importance of anatomy in medial patellofemoral ligament reconstruction. Am J Sports Med 2016;44(1):133–142. DOI: 10.1177/0363546515611652.
8. Solayar GN, Chinappa J, Harris IA, et al. A comparison of plain radiography with computer tomography in determining coronal and sagittal alignments following total knee arthroplasty. Malays Orthop J 2017;11(2):45–52. DOI: 10.5704/MOJ.1707.006.
9. Khalifa AA, Mullaji AB, Mostafa AM, et al. A protocol to systematic radiographic assessment of primary total knee arthroplasty. Orthop Res Rev 2021;13:95–106. DOI: 10.2147/ORR.S320372.
10. Solomin LN, Skomoroshko PV. Identification of femoral reference lines and angles in sagittal plane (preliminary report). J Bone Rep Recomm 2017;3:2. DOI: 10.4172/2469-6684.100041.
11. Vilenskiy VA, Solomin LN, Utekhin AI. Femur deformity correction planning in sagittal plane using mechanical axis. J Limb Lengthen Reconstr 2021;7:8–13. DOI: 10.4103/jllr.jllr_14_21.
12. Chung BJ, Kang YG, Chang CB, et al. Differences between sagittal femoral mechanical and distal reference axes should be considered in navigated TKA. Clin Orthop Relat Res 2009;467(9):2403–2413. DOI: 10.1007/s11999-009-0762-5.
13. Müller M, Crucius D, Perka C, et al. The association between the sagittal femoral stem alignment and the resulting femoral head centre in total hip arthroplasty. Inter Ortho 2011;35:981–987. DOI: 10.1007/s00264-010-1047-z.
14. Kingsley PC, Olmsted KL. A study to determine the angle of anteversion of the neck of the femur. J Bone Joint Surg 1948;30(3):745–751. PMID: 18109784.
15. Yau, WP, Chiu, KY, Tang, WM, et al. Coronal bowing of the femur and tibia in Chinese: its incidence and effects on total knee arthroplasty planning. J Orthop Surg (Hong Kong) 2007;15:32–36. DOI: 10.1177/230949900701500108.
16. Lee YK, Yeom J, Jang BW, et al. Reliability of measuring lateral bowing angle of the femur in patients with atypical femur fractures. J Orthop Surg (Hong Kong) 2019;27(3). DOI: 10.1177/2309499019881475.