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Influence of limb position on femoral neck anteversion angle measurement during computed tomography imaging

Rika Shigemoto, Takehiko Matsushita [*], Kyohei Nishida, Kanto Nagai, Yuta Nakanishi, Tetsuya Yamamoto, Tomoyuki Matsumoto, Noriyuki Kanzaki, Yuichi Hoshino, Ryosuke Kuroda

Department of Orthopaedic Surgery, Kobe University Graduate School of Medicine, Japan

A R T I C L E I N F O

Keywords:
Computed tomography
Femoral anteversion
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A B S T R A C T

Background: The femoral neck anteversion angle has been used as a surgical indicator for hip and patellofemoral joint disorders. However, the influence of limb position on femoral neck anteversion angle measurements during imaging remains unclear. Therefore, this study aimed to investigate the influence of limb position on femoral neck anteversion angle measurements.

Methods: Computed tomography images of 20 femurs from 10 patients were obtained. The angle between the line passing through the center of the femoral head and the center of the femoral neck and the tangential line of the femoral posterior condyles on axial slices was measured as the femoral neck anteversion angle. Raw femoral neck anteversion angle data was defined as the original femoral neck anteversion angle. The cutting direction of the axial plane was changed from −20° to 20° in 5° increments to simulate limb position changes for each of the following measurements: hip flexion/extension, abduction/adduction angles, and their combined directions. The femoral neck anteversion angle was measured under each condition, and the change in the angle was calculated. The correlation between hip angle and femoral neck anteversion angle change was analysed by Spearman's rank correlation coefficient.

Results: The mean original femoral neck anteversion angle was 17.6°. There was a strong negative correlation between hip flexion/extension change and femoral neck anteversion angle change ($r = -0.96$, $p < 0.001$). There was a weak correlation between hip adduction/abduction change and femoral neck anteversion angle change ($r = 0.35$, $p < 0.001$). The average maximum potential difference in femoral neck anteversion angle measurement combining flexion/extension and abduction/adduction was 21.0° ± 4.9°.

Conclusions: The femoral neck anteversion angle changed in association with changes in limb position, particularly with hip flexion and extension. Careful attention to limb position and conditions of the slice is needed to consistently evaluate the femoral neck anteversion angle.

1. Introduction

The femoral neck anteversion angle (FNAA) is an anatomical indicator of torsion in femoral morphology. Many studies have focused on the relationship between the FNAA and knee and hip joint disorders. Studies on knee disorders have reported that an increase in the FNAA leads to abnormal patellar tracking and risk for patellar dislocation[1,2] and risk of anterior cruciate ligament injury.[3] In addition, a decreased FNAA is associated with specific impingement morphology and a limited range of motion in patients with femoroacetabular impingement.[4] Conversely, increased FNAA levels are associated with increased labral tears,[5] hip pain in young female athletes, and hip dysplasia.[6,7]

The FNAA is commonly measured by physical examination,[8] radiography,[9] ultrasound,[10] computed tomography (CT),[11–14] and magnetic resonance imaging.[15,16] Clinically, CT is frequently used because of its usability, and several studies discuss the use of specialized software.[17,18] Accurate measurements are required because the FNAA value determines the target correction angle when performing osteotomies, such as femoral derotational osteotomies. Various methods of measuring the FNAA using CT have been reported. In previous reports, the limb

* Corresponding author. Department of Orthopaedic Surgery, Kobe University Graduate School of Medicine, 7-5-1 Kusunoki-cho, Chuo-ku, Kobe, Hyogo, 650-0017, Japan.

E-mail address: matsushi@med.kobe-u.ac.jp (T. Matsushita).

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Table 1
Patient demographics.

Number of patients	10
Age (years)	32 ± 20
Sex (n)	
Male	5
Female	5
Height (cm)	164 ± 9
Weight (kg)	67 ± 17
BMI (kg/m2)	25 ± 5
Diagnosis (number of patients)	
Knee osteoarthritis	3
Patellar dislocation	4
Anterior cruciate ligament injury	3

Data are presented as mean ± SD.

positions during CT imaging were typically described as supine or with the lower extremities extended. In the clinical setting, patients often have hip or knee contractures[19] and abnormal knee rotational alignments,[20,21] and the neutral limb position differs among patients. However, the manner in which a patient's limb is positioned during CT imaging, including hip extension/flexion, abduction-adduction, and rotation, has not been clearly mentioned in previous studies. Therefore, the influence of the limb position on FNAA measurements during CT imaging remains unknown.

This study aimed to investigate the influence of the limb position on FNAA measurements during CT imaging. We hypothesized that changes in limb position during CT would significantly affect FNAA measurements. Understanding the impact of limb position on FNAA measurements may allow for more precise measurements with reduced variability.

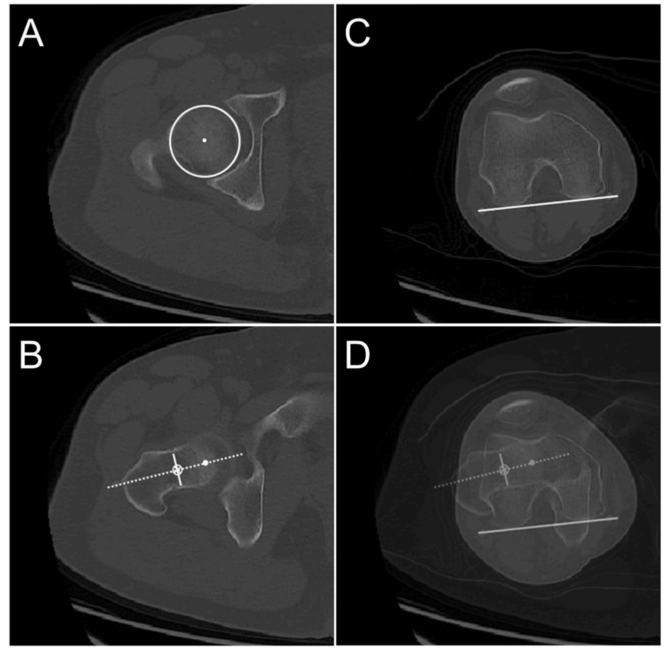

Fig. 1. Axial CT images showing (A) the femoral head center (B) the femoral neck and projected femoral head centers connected by a dotted line (C) the posterior femoral condyle tangent line (D) the FNAA angle measured between dotted and solid lines. CT, computed tomography; FNAA, femoral neck anteversion angle.

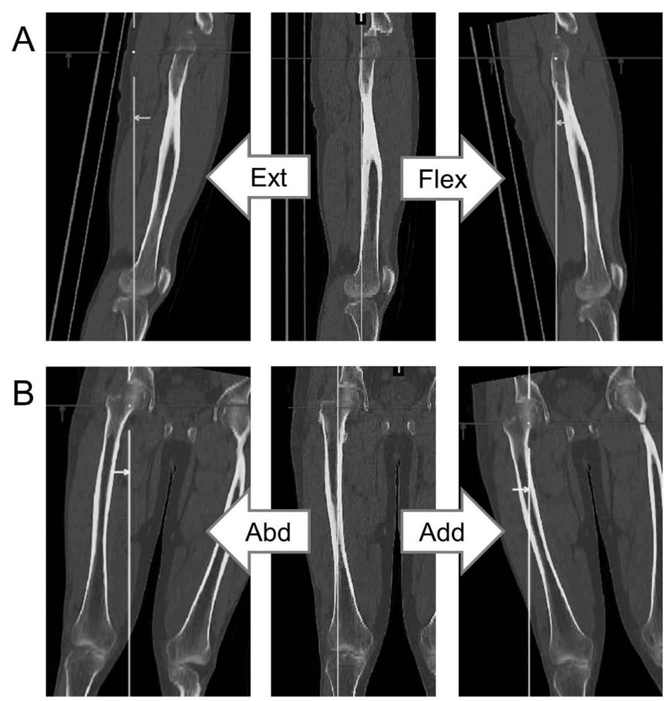

Fig. 2. Limb position change simulation. Simulation of 5° change from the original position (middle) of (A) extension (left) or flexion (right) or (B) abduction (left) or adduction (right). Each angle change was adjusted from −20° to 20° by 5° increments.

2. Materials and methods

A pilot study was conducted with a small sample of cases to estimate the effect size of the correlation between the two variables of hip angle and change in FNAA (ΔFNAA) measurement. The results of the pilot study indicated a large effect size of approximately 0.7, both between the flexion/extension and the ΔFNAA variables, and between the abduction/adduction and the ΔFNAA variables. Based on this estimate, an a priori power analysis was conducted using G*Power 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany)[22] to determine the required sample size needed for this study. The power analysis results indicated that a total sample size of 16 individuals was sufficient to detect a correlation of 0.7 or greater between the two variables of interest with a power of 0.95 and a significance level of 0.05. Considering the possibility that a higher effect size was estimated than was the case, this study included 20 whole lower extremity CT scans from 10 patients with knee joint diseases, such as anterior cruciate ligament injury, patellar dislocation, and knee osteoarthritis (5 males and 5 females) (Table 1).

Institutional review board approval and informed consent were obtained from all patients.

2.1. Measurement methods

CT was performed using a 320-slice CT system (Aquilion ONE/GENESIS Edition, Canon Medical Systems, Otawara, Japan) with 5 mm-slice thickness. During the CT scan, patients were placed in a relaxed supine position with the leges fully extended. No special equipment was used to immobilize the lower limbs. After extracting Digital Imaging and Communications in Medicine data from the Picture Archiving and Communication System software, the image data were imported into Mimics software (Materialise, Leuven, Belgium). FNAA measurements and axial slice angle changes were performed using the software.

FNAA levels were measured using the method described by Reikerås et al.[12] First, the axial slice with the largest femoral head diameter was selected, and the center of the femoral head was identified. Second, an axial slice at the middle of the femoral neck was selected, and the center of the neck was identified. The center of the femoral head was projected and a straight line was drawn connecting the two points. Third, an axial

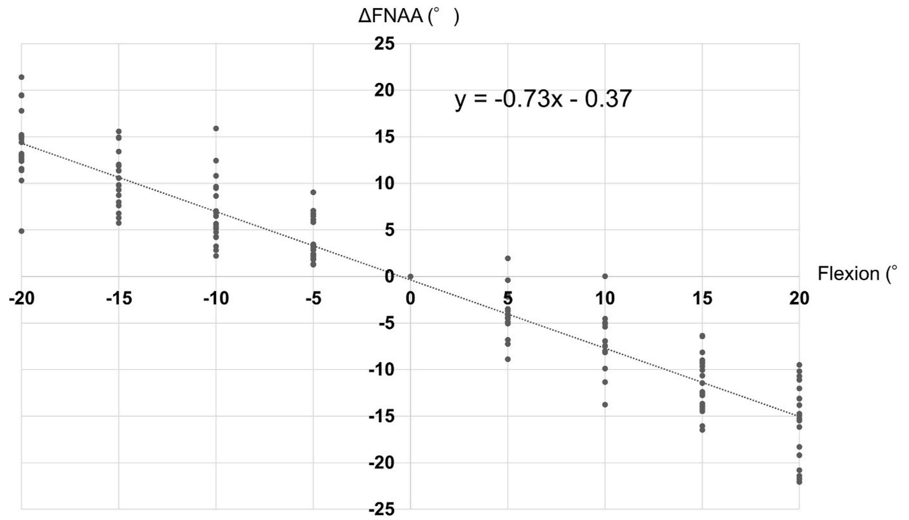

Fig. 3. A scatter plot of hip flexion/extension vs. ΔFNAA. FNAA, femoral neck anteversion angle.

slice at the middle level of the femoral posterior condyle was selected and a tangential line was drawn to the posterior condyle. The angle between the two straight lines was measured using the FNAA (Fig. 1). The raw FNAA data were defined as the original FNAA.

To accurately assess the impact of limb position on the FNAA measurements, the axial cutting plane was inclined in various directions to simulate limb position changes (Fig. 2). The simulation was performed referring to a previous report in which the angle of 3D-CT lower limb model was virtually changed.[23] The flexion/extension or abduction/adduction angles were adjusted in 5° increments from −20° to 20°. The combination of flexion/extension and abduction/adduction angles was adjusted from −10° to 10° at 5° intervals. The FNAA was remeasured in each of the changed slices, and the angular change from the original FNAA was calculated as the ΔFNAA.

To evaluate possible differences in the measurement value, the highest and lowest values for the ΔFNAA were identified from 25 angle patterns with a combination of hip flexion/extension and adduction/abduction. The difference between the highest and lowest values of the ΔFNAA (the highest value – the lowest value) was considered the possible maximum error (ME).

2.2. Statistical analysis

All statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R (R Foundation for Statistical Computing, Vienna, Austria). More precisely, it is a modified version of R commander designed to add statistical functions frequently used in biostatistics.[24] Spearman's rank correlation coefficient was used to analyse the correlation between changes in hip flexion/extension or adduction/abduction angle and the ΔFNAA. Statistical significance was set at $p < 0.05$. Two orthopaedic surgeons with more than 8 years of experience performed the FNAA measurement to assess the inter-rater reliability and a high interrater reliability with the inter-class correlation coefficient (ICC) of 0.96 was confirmed as reported in previous studies.[25,26]

3. Results

The patient demographics are shown in Table 1. Six knees of three patients with knee osteoarthritis (OA) were included. Of the six knees. two knees were Kellgren-Lawrence grade 1 and four knee were grade 2.[27] No obvious osteophyte on the posterior femoral condyle was identified that could affect the FNAA measurements. Hip OA was not

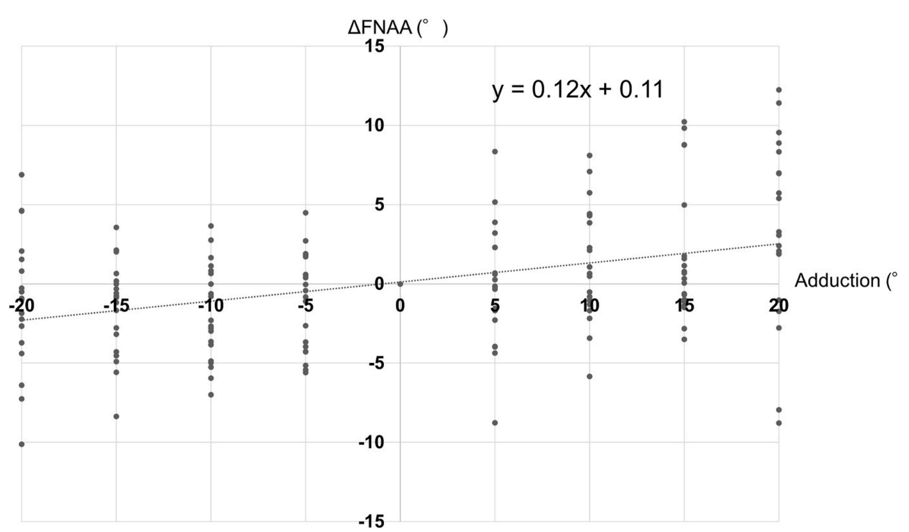

Fig. 4. A scatter plot of hip abduction/adduction vs. ΔFNAA. FNAA, femoral neck anteversion angle.

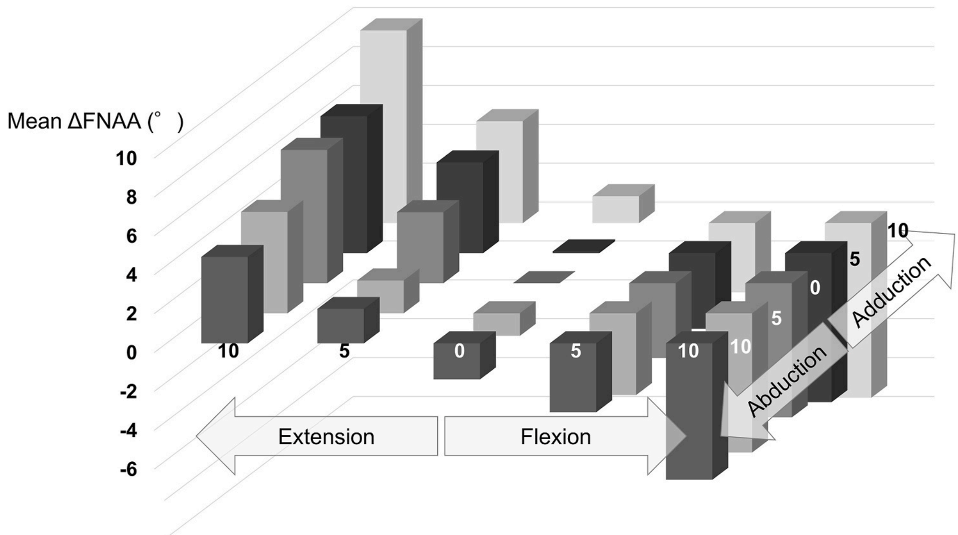

Fig. 5. The ΔFNAA in combination with hip flexion/extension and adduction/abduction angles. The horizontal axis represents hip flexion/extension, the depth represents adduction/abduction, and the vertical axis represents the ΔFNAA.
FNAA, femoral neck anteversion angle.

observed in any of the included patients. No significant limitation in the range of motion of the hip and knee joints were noted.

The mean original FNAA measurement of the 20 included legs from 10 patients was 17.6° ± 15.3°, with a minimum value of −13.5° and maximum value of 40.7°. A scatter plot of hip flexion/extension versus the FNAA is shown in Fig. 3. The FNAA tended to decrease with an increase in hip flexion, showing a strong negative correlation ($r = -0.96$, $p < 0.001$). Linear regression analysis showed that the FNAA decreased by 0.73° as the hip flexion increased by 1° (Fig. 3).

A scatter plot of hip adduction/abduction vs. the FNAA is shown in Fig. 4. The FNAA measurements tended to increase with changes in hip adduction, indicating a significantly weak positive correlation ($r = 0.35$, $p < 0.001$). Linear regression analysis indicated that the FNAA increased by 0.12° with every 1° increase in hip adduction (Fig. 4).

A graph depicting hip flexion/adduction combinations and the ΔFNAA is shown in Fig. 5. The average ME was 21.0° ± 4.9° (13.8°–33.7°)

4. Discussion

The most important finding of this study was that the FNAA measurement changed depending on the hip angle; in particular, the change was strongly correlated with hip flexion-extension changes.

Previous studies have reported that FNAA values change significantly depending on the imaging method used.[28,29] For example, Morvan et al. examined the difference in FNAA measurements between CT and stereoradiography using a dry femur with a tilted table to change the hip flexion/extension and adduction/abduction angles.[30] They found that measurement values with CT changed significantly with flexion/extension changes, whereas those with stereoradiography did not change significantly. They also compared CT and stereoradiography measurements using patient data and reported that the difference between the two measurement values was negatively correlated with the hip flexion angle. These observations are consistent with our results and suggest that the limb position can significantly affect FNAA measurements using CT.

In the present study, a computer software was used to simulate changes in the hip angle by changing the axial slice angle. This method allowed for a detailed investigation of the relationship between limb position changes and FNAA measurements within the same patient dataset. Our findings showed a strong negative correlation between the FNAA values and hip flexion, while there was a weak positive correlation with hip adduction. The mechanism of the strong influence of hip flexion on FNAA values appears to be attributed to the change in the femoral neckline, which is determined by the center of the femoral head and neck. In association with hip flexion, the center of the head tended

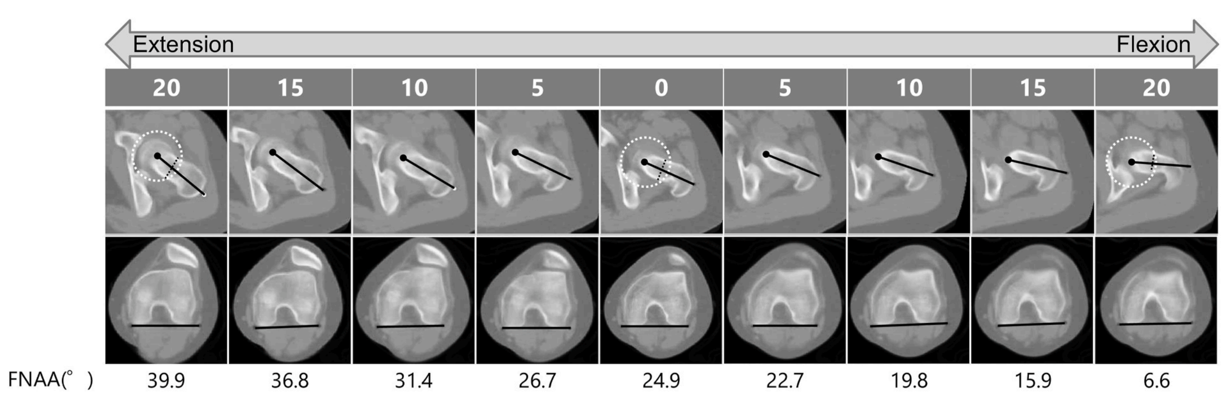

Fig. 6. An example of the FNAA change according to hip flexion/extension. The white dotted line indicates the projection of the femoral head. The black dotted lines are used to determine the center of the femoral neck.
FNAA, femoral neck anteversion angle.

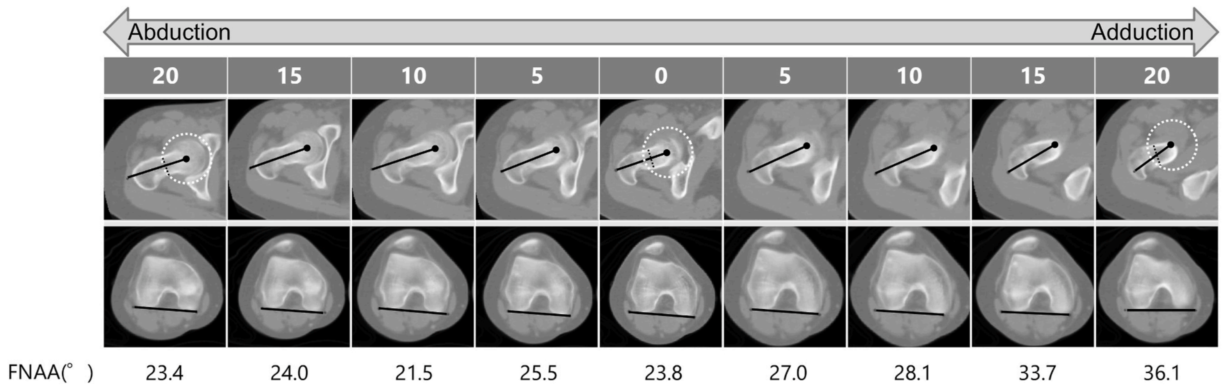

Fig. 7. An example of a FNAA change according to hip abduction/adduction. The white dotted line indicates the projection of the femoral head. The black dotted lines are used to determine the center of the femoral neck.
FNAA, femoral neck anteversion angle.

to be lower, whereas the middle of the femoral neck tended to be higher on the axial slice (Fig. 6). However, the tangent line at the posterior femoral condyle barely changed during the hip flexion. Meanwhile, changes in hip adduction/abduction were weakly correlated with changes in the FNAA values. The reason for this change also appears to be related to changes in the femoral neckline. Due to the misalignment of the center of the femoral head with the axis of the femoral neck, hip adduction/abduction alters the positional relationship between the femoral head center and the femoral neck center. In association with this change, the femoral neck axis changed, thereby changed the FNAA measurement value (Fig. 7). Taken together, the change in the femoral neckline appears to be the major contributor to the FNAA change due to the hip angle change.

In this study, the maximum possible ME owing to the combined change in extension/flexion and abduction/adduction was approximately 20°. The measurement error could cause a significant error in identifying the proper correction angle in rotational osteotomies or implant orientation in hip arthroplasty. Therefore, surgeons and radiologists should pay careful attention to the patient's limb position when evaluating the FNAA to avoid overestimation or underestimation of the FNAA. In particular, when the limb position is restricted during imaging owing to hip or knee joint contractures, it would be desirable to reconstruct the vertical axis and axial slice to accurately measure the FNAA.

5. Limitations

Although this study demonstrated a significant impact of limb position on FNAA measurements, it had some limitations. First, the sample size was relatively small with the inclusion of 20 femurs from 10 patients. However, the data were relatively consistent, and power analysis confirmed sufficient power to detect significance. Second, only CT images were used for analysis in this study. Other imaging modalities, such as radiography and magnetic resonance imaging, were not assessed. However, CT is the most frequently used method for obtaining FNAA measurements, and the results of our study are likely to be useful for clinicians. Third, we only used one method described by Reikerås et al.[12] to measure the FNAA. Other measurement methods were not used and the results may differ if other methods are used. Fourth, due to the small sample size the effects of gender, age, and specific diseases on the FNAA measurements were not examined. In addition, effects of osteophyte formation of the posterior femoral condyle on the measurement value were not examined since obvious osteophyte formation was not observed in this study. Finally, how the difference in FNAA values can affect clinical symptoms was not examined in this study, and the clinical significance of the differences in the FNAA needs to be addressed in the future.

Despite these limitations, our study provides meaningful information that clarifies the effect of limb position when evaluating the FNAA using CT.

6. Conclusions

The FNAA changed in association with changes in the virtual limb position. This trend was particularly noticeable for hip flexion and extension. Careful attention must be paid to the limb position and conditions of the slice to consistently evaluate the FNAA.

Informed consent:

Institutional review board approval and informed consent were obtained from all patients.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committees and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the ethics committee of Kobe University Hospital (B190030).

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Declaration of interest

The author(s) have no conflicts of interest relevant to this article.

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