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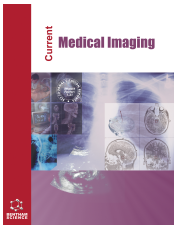

RESEARCH ARTICLE

Femoral Neck Shaft Angle Measurement for Differentiating Femoral Head Stress Fracture from Avascular Necrosis

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Abstract:

Objective:

The study aimed to evaluate whether the measurement of Femoral Neck Shaft Angle (FNSA) can be helpful in differentiating femoral head Stress Fracture (SF) from Avascular Necrosis (AVN).

Methods:

From September 2019 to April 2022, sixty-four patients [median age 32.0 years, interquartile range (IQR) 23.0–39.0 years] who underwent both hip radiograph and Magnetic Resonance Imaging (MRI) and diagnosed as femoral head SF or AVN were included in our retrospective study. Patients were divided into as having either femoral head SF (n = 34) or AVN (n = 30). The FNSA was measured in anteroposterior hip radiography. Continuous values were compared using the Mann-Whitney U test. The assessment of the predictive value of FNSA for femoral head SF was performed by Receiver Operating Characteristic (ROC) analysis.

Results:

The FNSA was significantly higher in patients with SF (median 133.5°, IQR 128.0–136.7°) than those with AVN (median 127.5°, IQR 124.0–132.0°) (p = 0.001). In addition, the FNSA was significantly higher in SF femurs (median 134.8°, IQR 129.2–137.4°) than in contralateral normal femurs (median 127.1°, IQR 124.3–132.5°) in patients with unilateral femoral head SF (n = 30) (p < 0.001). In ROC analysis, the sensitivity, specificity, and Area Under the Curve (AUC) for predicting the femoral head SF were 77.3%, 63.3%, and 0.785 (95% confidence interval: 0.666–0.905), respectively, at a cutoff of 130.2°.

Conclusion:

Increased FNSA was associated with femoral head SF; thus, measurement of FNSA could be helpful for differentiating femoral head SF from AVN.

Keywords: Radiography, Femoral neck shaft angle, Stress fracture, Avascular necrosis, Differentiation, Femoral head.

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1. INTRODUCTION

Femoral head Stress Fracture (SF) and Avascular Necrosis (AVN) have been recognized as causes of acute hip pain and risk factors for femoral head collapse [1, 2]. If left untreated, the process of femoral head SF and AVN can be progressive; thus, early diagnosis of the diseases is important [3]. However, it is usually difficult to differentiate femoral head SF from AVN since these two conditions have overlapping clinical and imaging characteristics [4].

Previous studies have reported helpful imaging findings and clinical history to differentiate between the femoral head SF and AVN. On MRI, the shape of the low signal intensity band can be useful in that the band is smooth and concave to the articular surface in AVN, but is irregular and convex to the articular surface in SF. Furthermore, a history of corticosteroid

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intake or alcohol abuse is associated with AVN [4 - 6]. However, it is still often challenging to differentiate between the two conditions despite these imaging and clinical findings, especially if the imaging findings described above are not obtained. Therefore, we aimed to find other imaging clues to help differentiate these two conditions.

In a previous study, femoral neck shaft angle (FNSA) was reported to be associated with the location of femoral SF, and coxa valga which increased FNSA > 135° was related to femoral head SF [7]. However, the published information regarding the clinical value of FNSA measurement for the diagnosis of femoral head SF or AVN is scarce. Therefore, the purpose of our study was to evaluate whether the measurement of FNSA could be helpful in differentiating femoral head SF from AVN. We anticipate that utilizing FNSA will assist physicians in distinguishing between these two diseases, ultimately benefiting the patients involved.

2. MATERIALS AND METHODS

2.1. Study Population

This was a retrospective study, approved by the Institutional Review Board (IRB with no. AFCH-2022-04-009), and the requirement for informed consent was waived.

Of the patients with hip pain and no trauma history, who underwent their first hip MRI from September 2019 to April 2022 in a tertiary care hospital, those diagnosed with a femoral head SF or AVN were selected for this study. Among the patients, those 1) undergoing only hip MRI without plain radiograph, 2) with any history of hip or femoral surgery, 3) with existing femoral head deformity due to previous trauma, inflammation, *etc*., 4) diagnosed with malignancy within 1 year, and 5) with discordant results (SF *vs*. AVN) failing to reach consensus between two radiologists, were excluded. Finally, 64 patients were included in this study. Then, the patients were divided into two groups of femoral head SF *vs*. AVN by retrospective review of hip MRI.

2.2. Imaging Protocol of Hip MRI

MRI examinations were performed by using a 3.0-T MR scanner (Discovery MR, 750w, GE Healthcare) with the non-enhanced hip protocol. The standard protocol consisted of T1-weighted axial [Repetition Time (TR)/Echo Time (TE) 688/18 ms, 4mm slice thickness, 0.5-mm gap] and coronal images (TR/TE 823/23 ms, 4mm slice thickness, 0.5mm gap), T2-weighted with Fat Saturation (FS) axial (TR/TE 4478/61 ms, 4mm slice thickness, 0.5-mm gap) and coronal images (TR/TE 5802/74 ms, 4-mm slice thickness, 0.5-mm gap), and Short Tau Inversion Recovery (STIR) coronal image (TR/TE 8387/54 ms, inversion time 150 ms, 4mm slice thickness, 0.5mm gap) using a 23-channel body coil with a 44 × 44 cm field of view and 384 × 256 acquisition matrix.

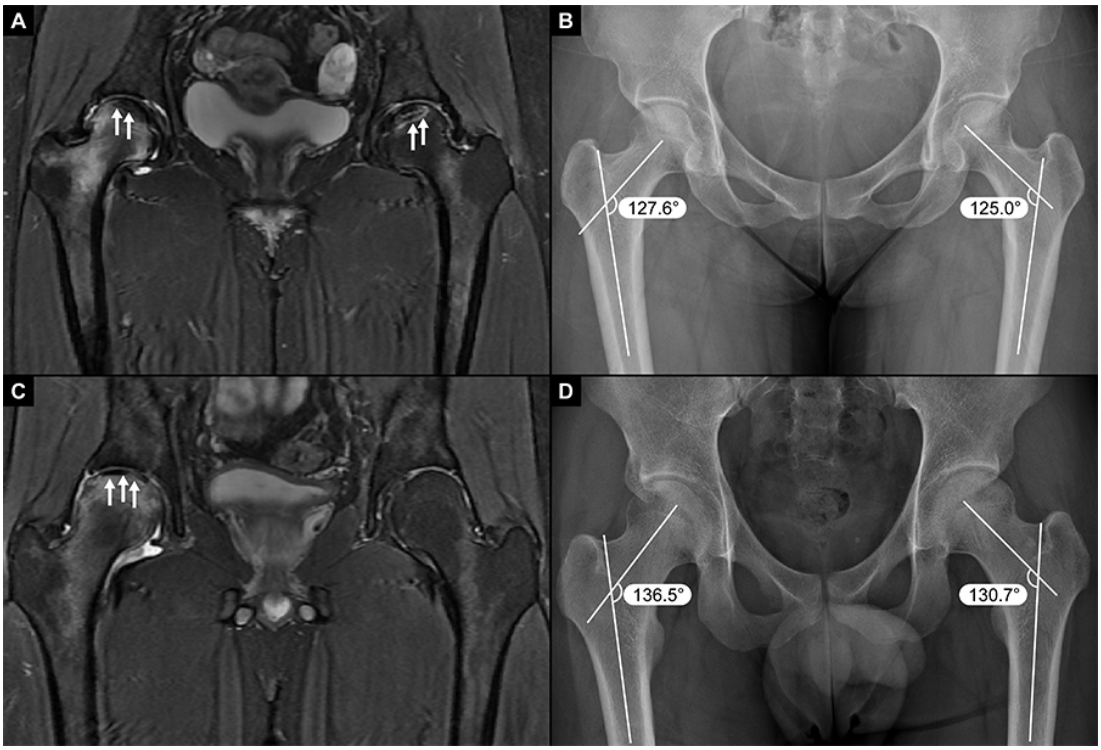

Fig. (1). Representative cases of femoral head Stress Fracture (SF) and Avascular Necrosis (AVN). In a 32-year-old woman diagnosed with bilateral femoral head AVNs, (**A**) hip MRI showed bone marrow edema with concave bands/lines (arrows) on the articular surface at bilateral femoral heads and (**B**) hip Anteroposterior (AP) radiograph showed normal Femoral Neck Shaft Angle (FNSA) at bilateral femurs. In a 31-year-old man diagnosed with right femoral head SF, (**C**) hip MRI showed bone marrow edema with convex fracture line (arrows) at right femoral head and (**D**) hip AP radiograph showed coxa valga at right femur (FNSA, right = 136.5°, left = 130.7°).

2.3. Image Analysis

Radiograph and MRI examinations of the study population were retrospectively reviewed by two radiologists (with 6 and 7 years of experience in musculoskeletal imaging). When there were disagreements in findings between the two radiologists, consensus was reached through discussion.

Femoral head SF and AVN were diagnosed based on specific MRI findings, including double-line sign, shape of low signal intensity band on MRI, and clinical history, such as steroid intake or alcohol abuse [4 - 6]. The FNSA was measured on standing hip anteroposterior (AP) radiographs obtained on the same day of the MRI scan for each patient. A minimum of two weeks separated the interpretations of radiographs and MRI scans to reduce the potential for recall bias. Reviewers were blinded to any patients' information, such as the side of the lesion (right or left or bilateral) involved in the femur when measuring FNSA on the radiograph. The FNSA was measured as the angle between the axis of the femoral shaft and neck [8, 9]. Then, the FNSA was classified into coxa vara, normal, or coxa valga as follows: FNSA < 120°, coxa vara; 120° ≤ FNSA ≤ 135°, normal; and FNSA > 135°, coxa valga [10].

2.4. Clinical Information

Clinical information of the study patients, including age, sex, Body Mass Index (BMI), Numeric Rating Scale (NRS) at the time of clinical visit, follow-up period, interval periods between the clinical visit and MRI scans, and patients' history, such as smoking, corticosteroid intake, and alcohol abuse, was obtained from the electronic medical charts.

2.5. Statistical Analysis

Continuous variables have been expressed as median with Interquartile Range (IQR) and compared using the Mann-Whitney U test. Categorical values have been expressed as absolute numbers with percentages and compared using Pearson's chi-square or Fisher's exact tests. Inter-reader agreements for categorical and continuous values were assessed by Kappa (κ) statistics and Intraclass Correlation Coefficient (ICC), respectively. Kappa values were interpreted as follows: less than 0.20, poor; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, good; and greater than 0.81, excellent agreement. ICC results have been interpreted as follows: less than 0.50, poor; 0.50–0.75, moderate; 0.76–0.90, good; and greater than 0.90, excellent [11, 12]. The clinical value of FNSA for diagnosing femoral head SF has been expressed as the Area Under the Curve (AUC) with 95% Confidence Interval (CI) by Receiver Operating Characteristic (ROC) analysis. The cutoff point was determined where the sum of specificity and sensitivity was the maximum value. Statistical analysis was performed using IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., IBM), and P value < 0.05 was considered as statistically significant [13].

3. RESULTS

3.1. Patients' Baseline Characteristics

A total of 64 patients (median age: 32.0 years, IQR: 23.0 – 39.0 years) with 77 femurs were included in this retrospective study. Of the study patients, there were 34 patients with 38 femoral head SF (bilateral in 4 cases) and 30 patients with 39 femoral head AVN (bilateral in 9 cases). Table **1** shows the baseline characteristics of study patients. There were no significant differences in age, sex, BMI, NRS, follow-up periods, interval periods between the clinical visit to MRI scans, and patients' history, including smoking, corticosteroid intake, and alcohol abuse between the two groups. However, the FNSA was significantly higher in patients with SF than those with AVN (SF, median 133.5°, IQR 128.0° – 136.7° *vs*. AVN, median 127.5°, IQR 124.0° – 132.0°; p = 0.001). Furthermore, the proportion of coxa valga was significantly higher in patients with SF than those with AVN (42.1% *vs*. 10.3%, p = 0.005) (Fig. **1**).

Table 1. Baseline characteristics of the study population.

-	Stress Fracture*	Avascular Necrosis*	*p*-value	Total
Age (years)	31.0 (22.0 – 37.0)	33.0 (24.0 – 43.0)	0.168	32.0 (23.0 – 39.0)
Sex, n (%)	-	-	0.307	-
Men	32 (94.1)	26 (86.7)	-	58 (90.6)
Women	2 (5.9)	4 (13.3)	-	6 (9.4)
BMI (kg/m^2)	21.8 (20.3 – 22.9)	22.1 (20.9 – 24.3)	0.266	22.0 (20.5 – 23.2)
NRS	3.0 (3.0 – 4.0)	3.0 (2.0 – 4.0)	0.400	3.0 (3.0 – 4.0)
F/U periods (months)	13.0 (11.0 – 16.0)	14.0 (9.0 – 16.0)	0.992	13.0 (9.5 – 16.0)
Interval periods (days)**	9.0 (6.0 – 11.0)	9.0 (5.0 – 11.0)	0.859	9.0 (6.0 – 11.0)
Corticosteroid intake, n (%)	1 (2.9)	3 (10.0)	0.244	4 (6.3)
Alcohol abuse, n (%)	1 (2.9)	0 (0.0)	0.344	1 (1.6)
Smoking, n (%)	-	-	0.670	-
Non-smoker	5 (14.7)	7 (23.3)	-	12 (18.8)
Ex-smoker	12 (35.3)	10 (33.3)	-	22 (34.4)
Current smoker	17 (50.0)	13 (43.3)	-	30 (46.9)
FNSA (°)	133.5 (128.0 – 136.7)	127.5 (124.0 – 132.0)	0.001	129.6 (126.2 – 133.9)
FNSA classification, n (%)	-	-	0.005	-
Coxa vara	1 (2.6)	3 (7.7)	-	4 (5.2)

(Table 1) contd.....

-	Stress Fracture*	Avascular Necrosis*	*p*-value	Total
Normal	21 (55.3)	32 (82.1)	-	53 (68.8)
Coxa valga	16 (42.1)	4 (10.3)	-	20 (26.0)

Note: BMI: Body Mass Index, NRS: Numeral Rating Scale, F/U: Follow-up, FNSA: Femoral Neck Shaft Angle.
*There were 34 patients with 38 femoral head stress fractures (bilateral in 4 cases) and 30 patients with 39 femoral head avascular necrosis (bilateral in 9 cases).
**Days between the clinical visit and hip MRI examinations.
Continuous values have been expressed as median with interquartile range (25 – 75%).

The inter-reader agreements for FNSA and FNSA classification in the study population were 0.902 (95% CI 0.840–0.956) and 0.878 (95% CI 0.783–0.946), respectively.

3.2. Relationship between FNSA and Femoral Head SF

Except for 4 patients with bilateral femoral head SF and 9 patients with bilateral AVN, there were 30 patients with unilateral SF and 21 patients with unilateral AVN. When evaluating the FNSA in both the affected femur and the contralateral normal femur within the same patients (Table **2**), the SF femur showed significantly higher FNSA than the contralateral normal femur (SF femur, median 134.8°, IQR 129.2° – 137.4° *vs*. normal, median 127.1°, IQR 124.3° – 132.5°; $p < 0.001$). However, there was no significant difference in FNSA between the AVN femur and contralateral healthy femur (AVN femur, median 127.1°, IQR 123.6° – 131.8° *vs*. normal, median 128.0°, IQR 125.4° – 133.1°; $p = 0.374$).

In the ROC analysis, FNSA ≥ 130.2° was determined as the cutoff value for predicting the risk of femoral head SF, with 77.3% sensitivity, 63.3% specificity, and 0.785 AUC (95% CI: 0.666 – 0.905, $p < 0.001$) (Fig. **2**).

Table 2. FNSA between the Avascular Necrosis (AVN) or Stress Fractured (SF) femur and the contralateral normal femur in the same patient; 30 patients with unilateral SF and 21 patients with unilateral AVN.

-	Stress Fracture Femur (n=30)	Contralateral Normal (n=30)	*p*-value
FNSA (°)*	134.8 (129.2 – 137.4)	127.1 (124.3 – 132.5)	< 0.001
FNSA classification, n (%)	-	-	0.043
Coxa vara	1	0	-
Normal	15	24	-
Coxa valga	14	6	-
-	**Avascular necrosis femur (n=21)**	**Contralateral normal (n=21)**	***p*-value**
FNSA (°)*	127.1 (123.6 – 131.8)	128.0 (125.4 – 133.1)	0.374
FNSA classification, n (%)	-	-	0.507
Coxa vara	2	1	-
Normal	19	20	-
Coxa valga	0	1	-

Note: FNSA: Femoral Neck Shaft Angle.
*Results have been expressed as median with interquartile range (25 – 75%).

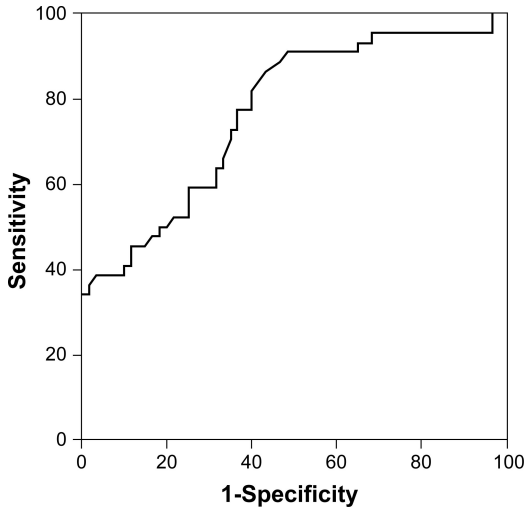

Fig. (2). The Receiver Operating Characteristics (ROC) analysis showed FNSA greater than 130.2° to be the cutoff value for predicting the risk of femoral head SF, with 77.3% sensitivity and 63.3% specificity. The Area Under the Curve (AUC) was 0.785 (95% confidence interval = 0.666 – 0.905).

4. DISCUSSION

In the present study, patients with femoral head SF showed significantly higher FNSA (133.5˚ *vs*. 127.5˚, $p = 0.001$) and proportion of coxa valga (42.1% *vs*. 10.3%, $p = 0.005$) than those with AVN. Furthermore, upon assessment of FNSA between the ipsilateral SF femur and the normal contralateral femur in the same patients, SF femur showed significantly higher FNSA than contralateral normal femur (134.8° *vs*. 127.1°, $p < 0.001$), while there was no significant difference in FNSA between ipsilateral AVN femur and normal contralateral femur (127.1° *vs*. 128.0°, $p = 0.374$). FNSA ≥ 130.2° represented a cutoff value for predicting the risk of femoral head SF based on ROC analysis.

Femoral head AVN represents an irreversible progression, which may lead to permanent joint failure, and SF can either progress toward epiphyseal collapse or resolve completely [14, 15]. There are some existing imaging and clinical findings, such as the smooth and concave shape of low signal intensity band, double line sign, and history of corticosteroid intake and alcohol abuse, which are helpful for differentiating femoral head AVN from SF [16, 17]; however, it is still often difficult to distinguish the two conditions. In this study, we suggested FNSA as a new potential and helpful diagnostic parameter for differentiating between the two conditions because our results showed increased FNSA to be significantly associated with femoral head SF.

Despite previous studies reporting the influence of FNSA on knee joint osteoarthritis or femur neck fracture, the biomechanics of femoral neck shaft anatomy for SF remains unclear [18, 19]. The two main opposing forces across the hip joints are the force generated by the abductor muscles and the body weight; thus, deviations from normal femoral neck shaft anatomy could impose excessive stress on the hip joint and femoral head/neck. For instance, in coxa valga, where the greater trochanter tip is located below the center of the femoral head, the lever arm of the abductor lever arm is decreased, and the abductor muscle is lengthened, consequently increasing force on the femoral head [20, 21]. Our findings are consistent with the biomechanics of femoral neck shaft anatomy affecting the femur according to the FNSA. Furthermore, FNSA greater than 130.2 ° could raise the risk of femoral head SF. These results suggest that FNSA could be a helpful parameter for differentiating the femoral head SF from AVN when it is ambiguous to distinguish the two conditions.

There are some limitations in this study. First, there may be selection bias due to its retrospective study design. In addition, patients without trauma were selectively chosen, and those with deformity due to previous inflammation were excluded. SF or AVN can also occur in these patients, and it is also difficult to distinguish these two conditions. Thus, future studies are needed. Second, though femoral head SF and AVN were diagnosed and classified based on the typical imaging findings and patients' clinical history with the consensus of two musculoskeletal radiologists, it might be sometimes difficult to distinguish the two conditions. Furthermore, patients with only bone marrow edema without a low signal band or lines were excluded, because there are other diseases that can present bone marrow edema on the femoral head, such as transient bone marrow edema syndrome. Third, FNSA was measured by manually drawing lines on each hip AP radiograph in the study patients. Though the inter-reader agreement for FNSA was excellent, manual measurements of FNSA may be inconsistent and inaccurate, which could result in overestimating or underestimating the clinical importance of FNSA. Therefore, further studies using automatic software system are required to clarify the relationship between FNSA and femoral head SF. Fourth, it was a single-center study with a relatively small sample size. Our hospital is a military hospital, and most patients are primarily soldiers, with the majority being young males. Further studies with larger sample sizes and diverse occupations are required to validate the results of our study for the general population. Finally, a comparison with the normal patients' group, not having any diagnosed pathology at the bilateral femur on MRI, was not conducted in this study. However, the FNSA of each femur in the same patients who had unilateral femoral head SF or AVN was compared, and it may provide better control of the variables than matching and analyzing different patients.

CONCLUSION

Increased FNSA was associated with femoral head SF, while there was no significant relationship between FNSA and femoral head AVN. Furthermore, patients with FNSA greater than ≥ 130.2° may be at risk of developing femoral head SF. Therefore, measurement of FNSA could be helpful for differentiating femoral head SF from AVN.

LIST OF ABBREVIATIONS

FNSA	=	Femoral Neck Shaft Angle
SF	=	Stress Fracture
AVN	=	Avascular Necrosis
MRI	=	Magnetic Resonance Imaging
AP	=	Anteroposterior
IQR	=	Interquartile Range
TR	=	Repetition Time
TE	=	Echo Time
FS	=	Fat Saturation
BMI	=	Body Mass Index
NRS	=	Numeric Rating Scale
ICC	=	Interclass Correlation Coefficient
AUC	=	Area under the Curve
CI	=	Confidence Interval

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the institutional review board and ethics committee of the Armed Forces Capital Hospital (IRB no. AFCH-2022-04-009).

HUMAN AND ANIMAL RIGHTS

No Animals were used that are the basis of this research. The study complied with the ethical principles of the Helsinki Declaration of 1964, revised by the World Medical

Organization in Edinburgh in 2000.

CONSENT FOR PUBLICATION

Informed consent was waived because the data were collected retrospectively and analyzed anonymously.

STANDARDS OF REPORTING

STROBE guidelines were followed.

AVAILABILITY OF DATA AND MATERIALS

The datasets generated and/or analyzed during the current study are not publicly available because the datasets belong to a military hospital.

FUNDING

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CONFLICT OF INTEREST

The authors have declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ACKNOWLEDGEMENTS

Declared none.

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