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Osteonecrosis of the Femoral Head Extent Estimation using Koo & Kim Angle and Volumetric Necrosis Measurement, and Assessing their Correlation with Functional Status of the Harris Hip Score: A Comparative Observational Study

Dr. Amit Saraf[1], Dr. Aneesh Kiran Malhotra[2]

Corresponding Author: Dr. Aneesh Kiran Malhotra

Abstract: ***Background: Numerous studies have indicated that the location and extent of necrotic lesions are crucial in determining the prognosis and occurrence of collapse in patients with osteonecrosis of the femoral head (ONFH). Despite the multiple classification systems, physicians face difficulties regarding the most appropriate strategy for measuring and assessing the extent of ONFH. Aim: To determine the extent of ONFH measured by Koo and Kim and volumetric necrosis measurements and assess their correlation with the Harris Hip Score (HHS) functional status in ONFH patients. Materials and methods: This study evaluated 87 adult patients with nontraumatic hip pain at an Indian tertiary care center. Patients underwent clinical assessment and bilateral hip magnetic resonance imaging (MRI) scans. The primary outcome correlated the extent of ONFH, measured by the Koo and Kim angle and volumetric assessment, with HHS functional status. The secondary outcomes assessed the impact of risk factors, including alcohol/smoking habits, steroid use, comorbidities, COVID-19 history, and pain duration, on the extent of ONFH. Results: The mean age of the study cohort was 40.6 ± 14.3 years. There was a strong negative correlation between the HHS, Koo, and Kim angles and necrosis volume. A large necrotic volume (>30% necrotic region) and large Koo and Kim angles [66% necrotic arc angle (NAA)] were strongly associated with poor HHS (<70°). Conversely, a small necrotic volume (<15% necrotic region) was correlated with good or excellent HHS (80-100). However, small Koo and Kim angles were less consistently correlated with HHS than necrosis volume. Alcohol/smoking status, steroid use, and pain duration were significantly correlated with HHS. A similar correlation was observed between necrosis volume and the Koo and Kim angles. Conclusion: Volumetric necrosis assessment provided a more detailed three-dimensional perspective of the necrotic area and showed a stronger correlation with the functional HHS score. Therefore, this method is more reliable in assessing the extent of ONFH.***

Keywords: Osteonecrosis, Femur head, Magnetic Resonance Imaging, Hip injuries, Necrosis

1. Introduction

Osteonecrosis of the femoral head (ONFH) results from pathophysiological disturbances that reduce blood supply, leading to cellular death, fracture, and articular surface collapse.[1, 2] This condition mainly affects individuals aged 20-40 years and progresses to functional impairment. ONFH-induced hip dysfunction significantly affects productivity during the active year. It necessitates hip replacement surgery in younger patients.[3] Annually, 20, 000-30, 000 new ONFH cases are diagnosed, representing approximately 10% of the 250, 000 total hip arthroplasties (THA) performed in the United States.[1] There is limited literature on ONFH prevalence and risk factors in the Indian context.[4] Thus, there is a need for focused research on ONFH in these demographic groups.

ONFH, a complex disorder, is triggered by risk factors, including corticosteroid use, alcohol consumption, smoking, hypercoagulation, bone marrow fat embolism, vascular endothelial dysfunction, and bone marrow edema in the femoral head.[5] The disorder progresses through the following stages: pre-collapse, early post-collapse (head depression <2 mm), and late post-collapse lesions (head depression >2 mm or acetabular changes), with outcomes classified as disease progression and arthroplasty conversion.[6] The extent of necrotic lesions is crucial for predicting a collapse in ONFH.[7] Accurately assessing the extent of femoral necrosis is challenging but essential for classification, prognosis, and discussing therapeutic options for ONFH management.

Current staging systems for ONFH use broad categories, such as sclerosis, subchondral fracture, collapse, and osteoarthritis, not emphasizing the size, location, and extent of avascular necrosis (AVN).[8] Accurate quantification of necrotic lesion size is essential for assessing patients with AVN. One of the most commonly used methods is calculating Koo's angle (modified Kerboul's angle[9]) on magnetic resonance imaging (MRI) scans, as Koo and Kim discovered that the degree of osteonecrosis was indicative of future collapse. There is a strong relationship between this index and the likelihood of collapse, and the index is a significant predictor of future collapse.[9, 10] However, the modified Kerboul angle and modified index of the extent of necrosis are 2-dimensional (2D) angular measurements that cannot accurately measure the true size of irregular 3D lesions.[9, 10]

Volumetric analysis of the necrotic lesion measured the lesion in 3 dimensions (3D). Such a 3D measurement was challenging to apply in routine use because of the complexity of the calculation. Advances in MRI software have made this technique easier.[11] Hindoyan KN *et al.*[12] compared different techniques used by Kerboul *et al.*, Koo and Kim, and Cherian *et al.*[13] and concluded that the extent of ONFH by Cherian et al. was more precise than Kerboul *et al.* while Koo & Kim methods and have excellent inter-observer reliability. In a

recent study conducted by Ansari *et al.*[14], the diagnostic performance of angular measurements (modified Kerboul Angle and modified index of necrotic extent) and 3D volumetric measurements of necrotic lesions based on MRI in predicting head collapse was evaluated. The volumetric method was more effective than the angular measurements in assessing the severity of lesion size and predicting future collapse. The study concluded that a necrotic lesion volume of 25% could serve as a potential cut-off beyond which future collapse of early ONFH can be predicted and aid in further management.[14]

Therefore, early intervention before collapse is critical for successful outcomes of joint-preserving procedures in patients with ONFH. Evidence shows that the Koo and Kim and volumetric measurement methods are reliable for estimating ONFH. However, their clinical significance and correlation with the functional status of Harris Hip Score (HHS) have not yet been studied. To the best of our knowledge, there is limited evidence assessing the extent of ONFH and its correlation with the HHS functional status of the patient.[15] Therefore, this study aimed to measure the extent of ONFH using the Koo and Kim method and volumetric necrosis measurements; it also assessed the correlation between these measurements and the functional status determined by the HHS.

2. Materials and Methods

This comparative study was conducted among 87 patients (87 hips) aged ≥ 18 years with non-traumatic hip pain at stages 1, 2 and 3 using Ficat and Artlet clasification[16] for ONFH visiting the Department of Orthopaedics, Teerthanker Mahaveer Medical College (TMCC) & Research Center (RC), Moradabad, between January 2023 and January 2024. According to the study protocol, details of the patient's history and clinical examination were obtained. The proforma included radiological examinations and HHS. Patients with radiographic findings suspicious or consistent with ONFH were included in the study, followed by MRI of both hips.

Patients with post-traumatic conditions, previous surgery for ONFH, prior analgesic use for at least one-week, lower limb deformities, congenital anomalies of the lower limb, or stage 4 or above ONFH according to the Ficat and Arlet classification[16] were excluded from the study. Approval was obtained from the College Research Committee and Institutional Ethics Committee of TMMC and RC, and written informed consent was obtained before the initiation of the study. Data privacy and confidentiality were maintained throughout the study.

Data Collection: Per the study protocol, standardized case report forms (CRFs) were used to capture data regarding alcohol/smoking, steroid use, smoking, patient-reported history of COVID-19 infection, any associated systemic illnesses, and duration of pain. HHS data were entered into a separate proforma.

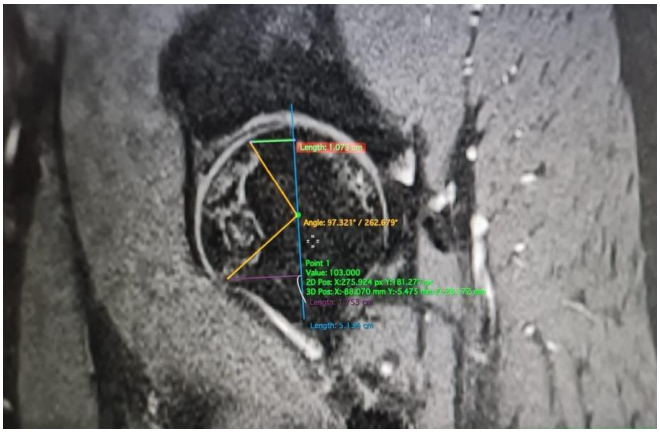
Study procedure: The patient's functional status was assessed using the HHS, while the extent of ONFH was estimated using the Koo and Kim angles as measured in the mid-coronal and mid-sagittal planes on hip MRI, followed by volumetric necrosis assessment.

HHS tool overview: HHS is a comprehensive assessment tool with a 100-point scale that evaluates pain, function, deformity, and motion. The pain domain evaluates the severity of pain, its impact on daily activities, and the need for pain medication. The function domain is divided into two sub-domains: daily activities, which include stair use, public transportation use, sitting, managing shoes and socks, and gait, which provides for limp, support needed, and walking distance. The deformity domain examined the discrepancies in hip flexion, adduction, internal rotation, and extremity length. The range of motion (ROM) domain assesses hip ROM, comprising six graded motions assigned an index factor and a maximum possible value. The total score is calculated by summing the scores of the four domains, with a total score of 70 or below considered poor, 70-80 as reasonable, 80-90 as good, and 90-100 as excellent. The HHS is widely used in clinical practice and research to evaluate the effectiveness of treatments and interventions for various musculoskeletal conditions.[15, 17]

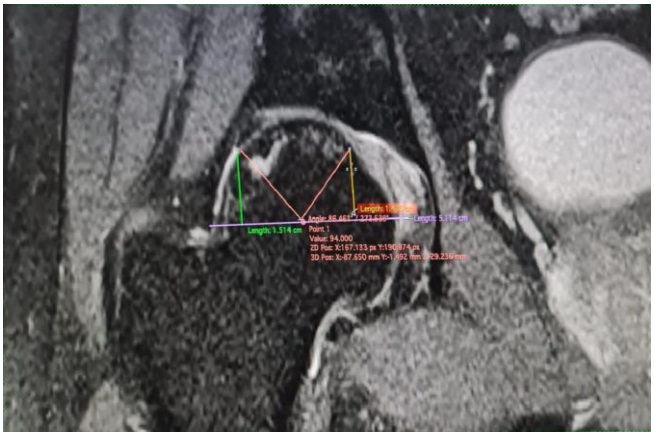
Koo & Kim Procedure: At least three readings of the Koo and Kim angles were taken, and then the mean angle was. The Koo and Kim method, an adaptation of the Kerboul angular measurements, was used to estimate the extent of ONFH. This method calculated two angular measurements on mid-sagittal and mid-coronal MRI.9, [10, 18]

The necrotic arc angle (NAA) measurement using the MRI hip is illustrated in Supplementary Fig 1. Utilizing concentric circles, the concentric center of the femoral head was identified, followed by drawing a horizontal line (A) through the center. From this line, two vertical lines (B) represent the medial and lateral ends of the necrotic lesion. Subsequently, one or two straight lines (C) are drawn from the concentric center to the points where the vertical lines (B) intersect the outer margin of the head, and the angle Alpha is measured.[19]

Measurement of the extent of osteonecrosis in the femoral head (ONFH) using the Koo and Kim angle in the Mid-sagittal and Mid-coronal plane is illustrated in Fig 1



A



B

Figure 1: Measurement of the extent of osteonecrosis in the femoral head (ONFH) using Koo and Kim angle in the Mid-sagittal and Mid-coronal plane

The Necrotic Arc Angle (NAA) was measured on the mid-coronal (A) and mid-sagittal (B) images using the Kim and Koo method, and the formula was used to quantify the number of necrotic sections.[9, 10]

Percentage of necrotic lesion = (A/180) * (B/180) *100

Based on these values, the hips were classified into small (33% NAA), medium (34-66% NAA), and large (>66% NAA) areas of necrosis. This method was called "index of necrotic extent" or "index of necrosis.[20]

Volumetric Necrosis Assessment: A freehand outline of the necrotic area was drawn on multiple 3 mm slices in T1 coronal planes. The areas of the necrotic region and the entire femoral head were measured in each coronal image. The area of the femoral head was divided by the location of the necrotic region to determine the two-dimensional measurement of the lesion. Volumetric measurements were computed as the sum of these measurements multiplied by the thickness of MRI slices.[7, 14] One observer performed a volumetric assessment of necrotic lesions on MRI at three periods (Fig 2 and Supplementary Fig 2). The necrosis volume of the hips was classified into small (<15% necrotic region), medium (15%-30% necrotic region), and large (>30% necrotic region).

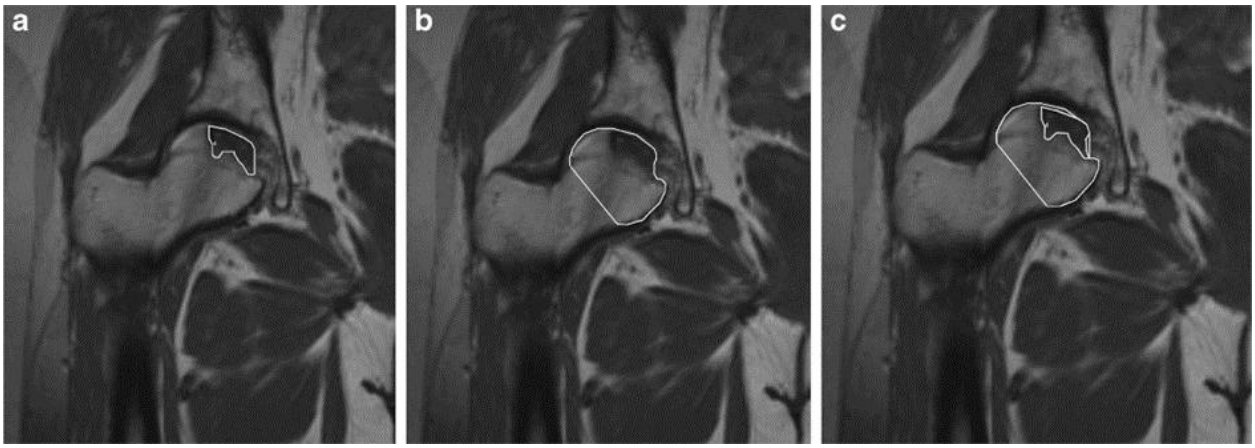


Figure 2: Coronal T1-weighted MRI images of a hip with osteonecrosis, as used for 3-D volumetric measurements. a, b, and c are Outline of the necrotic region

MRI Protocol: The standard protocol was followed at our institute. MRI using a 1.5 Tesla MR imaging apparatus (Siemens Magneto Avanto). The patients were placed supine with their feet first and their legs standardized with neutral abduction, adduction at 0° flexion, and 10° internal rotation. Non-enhanced magnetic resonance (MR) sequences were obtained using T1 and T2 weighted proton density fat saturation images in the axial, sagittal, and coronal planes. The data were stored in the DIACOM format and analyzed using the RadAnt DIACOM viewer.

Study outcomes: The primary outcome was the extent of ONFH, as measured by the Koo and Kim angle and volumetric assessment, and its correlation with the functional status of the hip using the HHS. This outcome assesses the correlation between necrosis extent and hip function. The secondary outcomes were compared between the Koo and Kim angles and volumetric assessment methods to determine the extent of ONFH and assess the impact of various risk factors including alcohol consumption, steroid use, smoking, comorbidities, history of COVID-19, and duration of hip pain.

Statistical Analysis: The collected data were entered into Microsoft EXCEL spreadsheet 2013. Statistical Package for Social Sciences (SPSS) software, IBM manufacturer, Chicago, USA, ver.28.0 was used for data analysis. Measures of skewness and Kolmogorov-Smirnov tests were used to check the normality of the data. Quantitative variables are presented using central tendencies (mean and median) and dispersion (standard deviation and standard error). Qualitative or categorical variables were presented as frequencies and proportions. Proportions were compared using the chi-square or Fisher's exact test, whichever was applicable. Spearman's rank and Pearson correlation coefficients were used to determine the correlations between different variables. All statistical tests were performed at a significance level of $P < 0.05$.

3. Results

The data collected from 87 patients (87 hips) were included in the final analysis.

The study cohort had a mean age of 40.6 ± 14.3 years, with 74.70% of the 65 patients being under 50 years old. There were 58 men (66.67%) and 29 women (33.33%), resulting in a 2: 1 male-to-female ratio (Supplementary Table 1)

Most hips (68.97%) had a poor (<70) HHS category. According to the Koo and Kim angle classification, the distribution revealed that most hips (74.71%) had small lesions (33% NAA). Similarly, in the volumetric assessment, the distribution showed that most hips 43 (49.43%) exhibited a small (<15% necrotic region) volume of necrosis (Supplementary Fig 3-5).

Table 1 summarizes the correlations between functional (HHS) and radiological (Koo & Kim, and Volumetric necrosis) parameters. Strong negative correlations were observed between HHS and both the Koo and Kim angles and necrosis volume. Large necrosis volume (>30%) and large Koo and Kim angles (>66% NAA) were strongly correlated with poor HHS (<70), while small necrosis volume (<15%) was associated with good or excellent HHS (80-100).

Table 2 summarizes the correlation between HHS, risk factors, and comorbidities. A negative correlation was observed between alcohol/smoking and HHS, with 51 (58.62%) patients in the poor HHS category (score <70). Similarly, steroid use showed a negative correlation with HHS, as 46 (52.87%) patients who used steroids had poor HHS scores (<70). Conversely, COVID-19 in 32 (36.78%) patients and comorbidities in 42 (48.28%) showed no correlation with HHS. The duration of pain was negatively correlated with poor HHS (<70), indicating that a longer pain duration was associated with worse clinical outcomes.

Table 3 summarizes the correlation between Koo and Kim angles and necrosis volume with risk factors and comorbidities. Alcohol/smoking is significantly associated with larger (>30%) and medium (15%-30%) necrosis volumes and large (>66% NAA) and medium (34%-66% NAA) Koo and Kim angles. Comorbidities, such as diabetes and obesity, correlate with necrosis volume and the Koo and Kim angles. Steroid use was significantly correlated with medium necrosis volume and medium Koo and Kim angle. A history of COVID-19 significantly correlates with the medium Koo and Kim angles. Longer pain duration (> one year) correlates with medium necrosis volume and medium Koo and Kim angle.

Table 1: Functional (Harris hip score) and radiological (Koo & Kim and Volumetric assessment) correlation in ONFH patients (N-87)

Variables		Harris Hip Score (HHS)				CC	P Value	CI
		Poor (<70) n (%)	Fair (70-80) n (%)	Good (80-90) n (%)	Excellent (90-100) n (%)			
Koo & Kim	Small (33% NAA)	38 (43.68%)	8 (9.20%)	9 (10.34%)	10 (11.49%)	-.381	<0.001	-552 to-179
	Medium (34%-66% NAA)	19 (21.84%)	NIL	NIL	NIL			
	Large (>66% NAA)	3 (3.45%)	NIL	NIL	NIL			
Volume of Necrosis	Small (<15% necrotic region)	16 (18.39%)	8 (9.20%)	9 (10.34%)	10 (11.49%)	-658	<0.001	-765 to-514
	Medium (15%-30% necrotic region)	42 (48.28%)	NIL	NIL	NIL			
	Large (>30% necrotic region)	2 (2.30%)	NIL	NIL	NIL			

Abbreviations: n-study population, CC-Correlation coefficient, CI-Confidence interval, NAA-Necrotic arc angle

Table 2: HHS correlation with risk factors and comorbidities in ONFH patients (N-87)

Variables		Harris Hip Score (HHS)				CC	**P-value**	CI
		Poor (<70) n (%)	Fair (70-80) n (%)	Good (80-90) n (%)	Excellent (90-100) n (%)			
Alcohol/ Smoking	Yes	51 (58.62%)	1 (1.15%)	1 (1.15%)	NIL	-.732	**<0.001**	-0.819 to-0.612
	No	9 (10.34%)	7 (8.05%)	8 (9.20%)	10 (11.49%)			
Comorbidities	T2DM	12 (13.79%)	4 (4.50%)	NIL	4 (4.60%)	-0.180	=0.095	-0.382 to 0.038
	T2DM & HTN	4 (4.60%)	NIL	1 (1.15%)	NIL			
	T2DM & Obesity	1 (1.15%)	NIL	NIL	NIL			
	HTN	5 (5.75%)	NIL	NIL	NIL			
	Obesity	9 (10.34%)	2 (2.30%)	1 (1.15%)	NIL			
	Obesity & HTN	2 (2.30%)	NIL	NIL	NIL			
	Psoriasis	NIL	1 (1.15%)	NIL	NIL			
	No Comorbidity	27 (31.03%)	5 (5.75%)	7 (8.05%)	6 (6.90%)			
Steroid use	Yes	46 (52.87%)	5 (5.75%)	1 (1.15%)	NIL	-0.517	**<0.001**	-0.695 to-0.338
	No	14 (16.09%)	3 (3.45%)	8 (9.20%)	10 (11.49%)			
COVID-19	Yes	32 (36.78%)	3 (3.45%)	6 (6.90%)	9 (10.34%)	0.146	=0.177	-0.073 to-0.352
	No	28 (32.18%)	5 (5.75%)	3 (3.45%)	1 (1.15%)			
Duration of Pain	0-6 months	20 (22.99%)	7 (8.05%)	9 (10.34%)	10 (11.49%)	-.371	**<0.001**	-.544 to-.168
	Six months-1 year	20 (22.99%)	1 (1.15%)	NIL	NIL			
	>1 year	20 (22.99%)	NIL	NIL	NIL			

Abbreviations: n-study population, HTN-hypertension, T2DM-Type 2 diabetes mellitus, CC-Correlation coefficient, CI-Confidence interval, HHS-Harris hip scores,

Table 3: Koo & Kim and Volume of necrosis correlation with risk factors and comorbidities (N=87)

Variables		Volume of Necrosis (%)			CC	P-value	CI	Koo & Kim			CC	P value	CI
		Small (<15% necrotic region)	Medium (15%-30% necrotic region)	Large (>30% necrotic region)				Small (33% NAA)	Medium (34%-66% NAA)	Large (>66% NAA)			
Alcohol/ Smoking	Yes	12 (13.79%)	39 (44.83%)	2 (2.30%)	-.665	<.001	-.770 to -.523	32 (36.78%)	18 (20.69%)	3 (3.45%)	0.412	**<0.001**	0.214 to 0.577
	No	31 (35.63%)	3 (3.45%)	NIL				33 (37.93%)	1 (1.15%)	NIL			
Comorbidities	T2DM	8 (9.20%)	8 (9.20%)	NIL	0.015	0.892	0-.203 to 0.231	10 (11.49%)	6 (6.90%)	NIL	0.230	**=0.032**	0.014 to 0.425
	T2DM & HTN	1 (1.15%)	2 (2.30%)	2 (2.30%)				3 (3.45%)	NIL	2 (2.30%)			
	T2DM & Obesity	1 (1.15%)	NIL	NIL				NIL	1 (1.15%)	NIL			
	HTN	NIL	5 (5.75%)	NIL				4 (4.60%)	NIL	NIL			
	Obesity	3 (3.45%)	9 (10.34%)	NIL				8 (9.20%)	4 (4.60%)	NIL			
	Obesity & HTN	NIL	2 (2.30%)	NIL				1 (1.15%)	1 (1.15%)	NIL			
	Psoriasis	1(1.15%)	NIL	NIL				1 (1.15%)	NIL	NIL			
	No Comorbidity	29 (33.33%)	16 (18.39%)	NIL				38 (43.68%)	6 (6.90%)	1 (1.15%)			
Steroid use	Yes	17 (19.54%)	33 (37.93%)	2 (2.30%	-.413	<0.001	-.578 to-.216	33 (37.93%)	16 (18.39%)	3 (3.45%)	0.319	**=0.003**	0.110 to 0.501
	No	26 (29.89%)	9 (10.34%)	NIL				32 (36.78%)	3 (3.45%)	NIL			
COVID-19	Yes	23 (26.44%)	25 (28.74%)	2 (2.30%	-.097	0.373	-.307 to 0.123	42 (48.28%)	6 (6.90%)	2 (2.30%)	-0.235	**=0.029**	-0.430 to-0.019
	No	20 (22.99%)	17 (19.54%)	NIL				23 (26.44%)	13 (14.94%)	1 (1.15%)			
Duration of Pain	0-6 months	41 (47.13%)	5 (5.75%)	NIL	0.078	0.472	-.141 to.290	43 (49.43%)	3 (3.45%)	NIL	-.295	**=0.005**	-.481 to-0.084
	Six months-1 year	2 (2.30%)	19 (21.84%)	NIL				15 (17.24%)	6 (6.90%)	NIL			
	>1 year	NIL	18 (20.69%)	2 (2.30%)				7 (8.05%)	10 (11.49%)	3 (3.45%)			

Abbreviations: n-study population, HTN-hypertension, T2DM-Type 2 diabetes mellitus, CC-Correlation coefficient, CI-Confidence interval, NAA-Necrotic arc angle

4. Discussion

To the best of our knowledge, this is the first study comparing angular and volumetric measurements to assess the extent of necrosis in ONFH and correlate it to the functional status of the hip using HHS and to study the associated risk factors. The findings of the current study indicate that male ONFH patients aged <50 years and those with a history of alcohol/smoking, steroid use, history of COVID-19 infection, duration of pain for > 1 year, and co-morbidities, including T2DM and obesity, are more likely to have poorer clinical/functional [(poor HHS <70) and radiological outcomes (Koo and Kim-large >66% NAA); (Volume of necrosis large >30% necrotic region)]. Both the Koo and Kim and volumetric necrosis methods have accurately assessed necrosis. However, volumetric assessment using detailed 3-D volumetric MRI is a precise method for determining the extent of necrosis and has shown a correlation with HHS.

The age distribution in the current study showed that 65 of the 85 patients (74.70%) were aged < 50 years. According to a study by Wang *et al.*, the average age of the patients with ONFH was 48 years. In line with these Asian studies, we assume that ONFH is more prevalent in young Asian individuals during their active years.[21] In the present study, 53 of 88 patients (60.00%) reported engaging in alcohol and smoking habits, whereas 52 patients (59.77%) reported a history of steroid use. A study conducted in North India by Goyal *et al*. found that steroid exposure was the leading cause of ONFH among patients, accounting for 44% of cases. In 30% of cases, alcohol exposure was identified as the second-most common risk factor. The study demonstrated that higher levels of alcohol and steroid consumption were associated with poorer clinical and radiological outcomes, such as lower HHS, increased pain levels, and a larger area of femoral head involvement, which aligns with the current study's findings.[22] In the current study, it was also observed that 50 patients (57.47%) reported a history of COVID-19. This finding is consistent with the five-case series of ONFH in individuals who recovered from COVID-19. Furthermore, it is crucial to acknowledge the potential risk of osteonecrosis that may result from possible high-dose corticosteroid treatment during the COVID-19 pandemic.[23] A retrospective study in Pennsylvania, in which 3-D volumetric MRI was deemed the most accurate method for measuring lesion size and served as the benchmark for comparison with other techniques.[24] A

different study revealed that necrotic lesions were located in the anterolateral and superior portions of the femoral head in the restructured 3D model, which aligned better with the anatomical location of the osteonecrotic lesions. The results also revealed that if the necrotic volume was more than 30% of the entire femoral head, there was also a larger collapsed region.[25]

According to Steinberg *et al*.7, volumetric measurements are considered to be more dependable and precise than angular measurements. Nevertheless, these researchers presented a correlation between volumetric and angular methods without assessing their reliability for prognosis. Koo & Kim [10] and Ha *et al*.9 have argued that angular methods are more suitable for clinical use than the Steinberg classification[14] based on necrotic volume because these methods are uncomplicated and easy to use. Furthermore, they suggested that angular methods are more effective at forecasting the likelihood of collapse than single-plane measurement methods. However, these researchers have not directly compared angular, volumetric, and locational classification systems. Therefore, accurately delineating the scope of ONFH presents a significant clinical challenge. As osteonecrosis treatment progresses, it is essential to use the most accurate measurement techniques to assess its effectiveness and determine appropriate management strategies. With advancements in conservative interventions, it is crucial to identify viable areas of bone tissue for preservation during surgery. The current study underscored that the modified Kerboul angle, also known as Koo's angle, may not offer a suitable evaluation of necrotic damage in patients with ONFH beyond the pre-collapse stage. In contrast, volumetric necrosis evaluation can achieve a more effective assessment.

The study's primary strength lies in assessing both the Koo and Kim angles and volumetric necrosis assessment to quantify the extent of ONFH, allowing for a comprehensive evaluation of the disease. This dual approach enhances the reliability of the findings. One of the strengths is that the measurements/readings for the Koo and Kim angles and the necrosis volume were obtained three times by the same observer to reduce the likelihood of errors or biases, including observer, measurement, and instrumental biases. Moreover, by correlating the extent of ONFH with HHS, this study offers valuable insight into the functional implications of this disease. This information is essential for informed clinical decision-making and optimising patient management. This study involved meticulous data collection, including detailed histories of alcohol consumption, steroid use, smoking habits, and comorbidities to better understand the factors influencing ONFH in India. Despite its robustness, this study had several limitations. As the study was conducted at a single center, the results may reflect institutional practices specific to that setting. They may not be universally applicable across different clinical environment, thus compromising the generalizability of the study findings. The potential for information bias may be factored into when patients respond to the HHS forms. Despite controlling for various variables, potential confounding factors, such as the duration and type of steroid use, variations in alcohol consumption, and other comorbid conditions, may have influenced the outcomes.

5. Conclusion

The study findings show a significant negative correlation between the extent of ONFH and functional outcomes. Large lesions (>66% NAA) of the Koo and Kim angle and a large volume of necrosis (>30% necrotic region) in the volumetric assessment correlated with poor HHS (<70). These findings highlight the significance of early and precise assessment of the extent of necrosis for predicting patient prognosis. Employing the Koo and Kim angles and volumetric assessment in the current study provided a comprehensive evaluation of the ONFH. It is important to note that both methods effectively determined osteonecrosis. However, volumetric evaluation offered a more detailed 3-D perspective of the necrotic area and showed a better correlation with the functional HHS score. This approach may be particularly beneficial in clinical practice, owing to its accuracy and potential capacity to comprehend the extent of the disease entirely. The study also showed significant correlations between functional outcomes and various risk factors, including alcohol consumption, smoking, and steroid use. These findings highlight the multifactorial etiology of ONFH and the need to address modifiable risk factors to improve patient outcomes. Surveillance of ONFH in these patients may help diagnose ONFH before the advanced collapse of the femoral head has occurred, providing an opportunity for timely treatment. However, we recommend further research to address these study constraints and to provide additional support for the findings of this study. Longitudinal multicenter studies with larger sample sizes are needed to assess the progression of ONFH and its impact on patient outcomes.

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