MAGNETIC RESONANCE IMAGING ASSESSMENT AND MRI-BASED STAGING OF AVASCULAR NECROSIS OF THE FEMORAL HEAD: A HOSPITAL-BASED OBSERVATIONAL STUDY FROM A TERTIARY CARE CENTRE IN NORTH INDIA

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ABSTRACT

Background: Avascular necrosis (AVN) of the femoral head is a progressive disorder resulting from compromised blood supply to the femoral head, leading to bone ischemia, structural collapse, and eventual degenerative arthritis. Early diagnosis is essential because therapeutic interventions are most effective before femoral head collapse occurs. Magnetic resonance imaging (MRI) is considered the most sensitive imaging modality for the detection and staging of AVN.

Objectives: To assess the MRI findings of avascular necrosis of the femoral head, determine the distribution of MRI-based disease stages, and evaluate the association between selected MRI features and disease severity among patients attending a tertiary care hospital in North India.

Methods: A hospital-based observational cross-sectional study was conducted in the Department of Radiodiagnosis of a tertiary care hospital in North India from March 2022 to June 2022. A total of 44 patients with clinically suspected AVN of the femoral head who underwent MRI evaluation were included using consecutive sampling. Demographic details, clinical characteristics, risk factors, and MRI findings were recorded using a structured data collection form. MRI assessment included evaluation of lesion characteristics, double-line sign, bone marrow edema, joint effusion, subchondral fracture, femoral head collapse, and staging according to the Association Research Circulation Osseous (ARCO) classification. Data were analyzed using SPSS version 25.0. Statistical significance was considered at $p < 0.05$.

Results: The mean age of participants was 41.2 ±11.3 years, and males constituted 70.5% of the study population. Hip pain was the most common presenting symptom (90.9%). Corticosteroid use (31.8%) and chronic alcohol intake (27.3%) were the most frequently identified risk factors. MRI demonstrated unilateral involvement in 56.8% of patients and bilateral involvement in 43.2%. The double-line sign was observed in 77.3% of cases, while bone marrow edema and joint effusion were present in 54.5% and 45.5% of patients, respectively. According to ARCO staging, Stage II disease

was most common (34.1%), followed by Stage III (31.8%). A significant association was observed between bone marrow edema and advanced disease stages (ARCO III–IV) ($p = 0.003$).

Conclusion: MRI is a highly valuable imaging modality for the diagnosis, characterization, and staging of avascular necrosis of the femoral head. The study highlights the predominance of intermediate-stage disease at presentation and demonstrates the association of bone marrow edema with advanced-stage AVN. Early MRI evaluation in high-risk individuals may facilitate timely intervention and improve clinical outcomes.

Keywords: Avascular necrosis; Femoral head; Magnetic resonance imaging; Osteonecrosis; ARCO staging; Bone marrow edema; Hip joint

INTRODUCTION

Avascular necrosis (AVN), also known as osteonecrosis of the femoral head, is a debilitating orthopedic condition resulting from compromised blood supply to the femoral head, leading to bone ischemia, cellular death, structural collapse, and eventual degenerative arthritis of the hip joint [1]. The disease predominantly affects young and middle-aged adults and is associated with considerable morbidity, loss of productivity, and deterioration in quality of life. Although the exact incidence varies geographically, AVN of the femoral head remains a significant cause of hip disability worldwide and frequently necessitates total hip arthroplasty in advanced stages [2].

The etiology of AVN is multifactorial and includes both traumatic and non-traumatic causes. Traumatic factors such as femoral neck fractures and hip dislocations can directly disrupt the vascular supply to the femoral head. Non-traumatic causes include prolonged corticosteroid therapy, excessive alcohol consumption, hemoglobinopathies, autoimmune disorders, coagulation abnormalities, and idiopathic factors [3]. Regardless of the underlying cause, interruption of blood flow initiates a cascade of ischemic changes that culminate in necrosis of the trabecular bone and marrow components. Disease progression is often insidious, and clinical manifestations may remain subtle during the early stages, making timely diagnosis challenging [4].

Early identification of AVN is crucial because therapeutic interventions are most effective before structural collapse of the femoral head occurs. Conventional radiography is frequently the first imaging modality employed in patients presenting with hip pain; however, radiographic findings are often normal during the initial stages of the disease and may fail to detect early ischemic changes [5]. Computed tomography (CT) can provide detailed evaluation of osseous architecture and subchondral fractures but lacks sufficient sensitivity for detecting early marrow abnormalities. Consequently, reliance solely on radiographs or CT may delay diagnosis and adversely affect patient outcomes [6].

Magnetic resonance imaging (MRI) has emerged as the imaging modality of choice for the diagnosis and staging of AVN owing to its superior soft tissue contrast and ability to detect early marrow alterations before radiographic abnormalities become apparent [7]. MRI demonstrates characteristic findings such as focal marrow signal changes, the double-line sign, geographic lesions, bone marrow edema, and subchondral fractures. Furthermore, MRI facilitates accurate assessment of lesion size, location, extent of femoral head involvement, and risk of collapse, all of which are critical determinants of prognosis and treatment planning [8]. Previous systematic reviews have reported high sensitivity and specificity of MRI for detecting early osteonecrosis, reinforcing its role as the diagnostic gold standard [9].

The Association Research Circulation Osseous (ARCO) classification and other staging systems increasingly incorporate MRI findings because disease stage strongly influences therapeutic decision-making. Patients diagnosed in pre-collapse stages may benefit from joint-preserving procedures such as core decompression, whereas advanced disease often requires arthroplasty [10]. Therefore, comprehensive MRI evaluation not only aids diagnosis but also guides management strategies and prognostication.

In India, AVN of the femoral head is commonly encountered in tertiary care centers owing to increasing use of corticosteroids, rising burden of chronic diseases, and improved access to advanced imaging facilities. However, there remains limited institutional data from North Indian populations regarding the MRI spectrum of AVN, stage distribution at presentation, and associated imaging characteristics. Local evidence is important because demographic profiles, risk factors, healthcare-seeking behavior, and disease presentation may differ from those reported in international literature.

Against this background, the present study was undertaken to assess the magnetic resonance imaging findings in patients diagnosed with avascular necrosis of the femoral head at a tertiary care hospital in North India. The objectives were to evaluate the demographic profile of affected patients, describe characteristic MRI features, determine the distribution of disease according to MRI-based staging, and analyze the relationship between MRI findings and disease severity.

METHODOLOGY

Study Design: A hospital-based observational cross-sectional study was conducted to assess magnetic resonance imaging (MRI) findings in patients diagnosed with avascular necrosis (AVN) of the femoral head.

Study Setting: The study was conducted in the Department of Radiodiagnosis of a tertiary care teaching hospital in North India. The institution serves as a referral center for patients from both urban and rural regions and is equipped with advanced MRI facilities for musculoskeletal imaging.

Study Duration: The study was conducted over a period of four months from March 2022 to June 2022.

Study Population: The study population comprised patients clinically suspected of having avascular necrosis of the femoral head and referred for MRI evaluation during the study period.

Inclusion Criteria

Patients of either sex aged 18 years and above.
Patients presenting with hip pain, limp, restricted hip movements, or clinical suspicion of avascular necrosis of the femoral head.
Patients undergoing MRI examination of the hip during the study period.
Patients willing to provide written informed consent.

Exclusion Criteria

Patients with contraindications to MRI such as cardiac pacemakers, cochlear implants, ferromagnetic implants, or metallic foreign bodies.
Patients with previous hip arthroplasty or major hip surgery.

Patients with inadequate or poor-quality MRI images precluding interpretation.
Patients unwilling to participate or provide informed consent.
Patients with known malignant lesions involving the hip region.

Sample Size: The sample size was calculated using the formula for estimation of a proportion:

[

$$n = \frac{Z^2 \times p \times q}{d^2}$$

]

Where:

n = required sample size
Z = 1.96 at 95% confidence level
p = anticipated prevalence of MRI-detected AVN among suspected cases (50%, used in absence of reliable local estimates to obtain maximum sample size)
q = 1 − p = 50%
d = allowable error = 15%

Substituting the values:

[

$n = \frac{(1.96)^2 \times 0.5 \times 0.5}{(0.15)^2}$]

[

n = 42.7

]

The minimum required sample size was approximately 43 participants. Considering feasibility and complete recruitment during the study period, a total of 44 patients were included in the study.

Sampling Technique: A consecutive sampling technique was employed. All eligible patients fulfilling the inclusion criteria and presenting during the study period were recruited until the required sample size of 44 was achieved.

Data Collection Tools and Procedure: After obtaining written informed consent, demographic and clinical details including age, sex, presenting symptoms, duration of symptoms, history of trauma, corticosteroid use, alcohol consumption, and relevant comorbidities were recorded using a predesigned case record form. MRI examinations of the affected hip or both hips were performed using a standard institutional musculoskeletal imaging protocol. Sequences included T1-weighted, T2-weighted, Short Tau Inversion Recovery (STIR), and other routinely acquired sequences in multiple planes. MRI images were interpreted independently by experienced radiologists. Imaging findings assessed included laterality of involvement, lesion location, extent of femoral head involvement, double-line sign, bone marrow edema, joint effusion, subchondral fracture, femoral head collapse, and MRI stage according to the Association Research Circulation Osseous (ARCO) classification. Data were recorded systematically and entered into a structured database for analysis.

Study Variables: Independent variables included age, sex, laterality of disease, duration of symptoms, history of corticosteroid intake, alcohol consumption, trauma, and associated risk factors. Dependent variables included MRI findings such as stage of AVN, lesion extent, presence of double-line sign, bone marrow edema, joint effusion, subchondral fracture, femoral head collapse, and other associated imaging abnormalities. The primary outcome measure was MRI-based assessment and staging of avascular necrosis of the femoral head.

Statistical Analysis: Data were entered into Microsoft Excel and analyzed using Statistical Package for the Social Sciences (SPSS) software version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were summarized using mean and standard deviation or median and interquartile range, as appropriate. Categorical variables were presented as frequencies and percentages. Associations between categorical variables were assessed using the Chi-square test or Fisher's exact test wherever applicable. A p-value of less than 0.05 was considered statistically significant.

Ethical Considerations: Written informed consent was obtained from all participants prior to enrolment. Confidentiality and anonymity of patient information were maintained throughout the study. Participation was entirely voluntary, and participants were free to withdraw from the study at any stage without affecting their medical care. The study adhered to the ethical principles outlined in the Declaration of Helsinki and its subsequent amendments governing biomedical research involving human participants.

RESULTS

A total of 44 patients diagnosed with avascular necrosis of the femoral head were included in the study. The mean age of participants was 41.2 ±11.3 years, with the highest proportion belonging to the 31–40-year age group. Males constituted the majority of cases (70.5%) (Table 1)

Table 1. Demographic Characteristics of Study Participants (N = 44)

Variable	Category	Frequency (n)	Percentage (%)
Age Group (years)	18–30	8	18.2
	31–40	14	31.8
	41–50	12	27.3
	>50	10	22.7
Sex	Male	31	70.5
	Female	13	29.5

Mean age: 41.2 ±11.3 years

Hip pain was the most common presenting complaint, followed by limping gait and restricted hip movements. Corticosteroid exposure and chronic alcohol intake were the predominant identifiable risk factors, while one-fourth of the cases were classified as idiopathic (Table 2).

Table 2. Clinical and Risk Factor Profile of Patients with AVN of Femoral Head (N = 44)

Variable	Category	Frequency (n)	Percentage (%)
Presenting Symptom*	Hip pain	40	90.9
	Limping gait	26	59.1
	Restricted hip movement	22	50.0
	Groin pain	18	40.9
Risk Factors	Corticosteroid use	14	31.8
	Chronic alcohol intake	12	27.3
	Previous trauma	7	15.9
	Idiopathic	11	25.0

*Multiple responses possible.

MRI evaluation demonstrated unilateral disease in more than half of the patients, whereas bilateral involvement was observed in 43.2% of cases. The double-line sign was the most frequent MRI finding, followed by bone marrow edema and joint effusion. Subchondral fractures and femoral head collapse were observed in a smaller proportion of patients (Table 3).

Table 3. MRI Characteristics of Avascular Necrosis of the Femoral Head (N = 44)

MRI Finding	Frequency (n)	Percentage (%)
Bilateral involvement	19	43.2
Unilateral involvement	25	56.8
Double-line sign	34	77.3
Bone marrow edema	24	54.5
Joint effusion	20	45.5
Subchondral fracture	11	25.0
Femoral head collapse	9	20.5

Assessment according to the ARCO MRI classification revealed that Stage II disease was the most common presentation, followed closely by Stage III. Approximately one-fifth of the patients had advanced Stage IV disease at the time of diagnosis (Table 4).

Table 4. Distribution of Cases According to ARCO MRI Stage (N = 44)

ARCO Stage	Frequency (n)	Percentage (%)
Stage I	6	13.6
Stage II	15	34.1
Stage III	14	31.8
Stage IV	9	20.5

A statistically significant association was observed between the presence of bone marrow edema and advanced-stage disease (ARCO Stages III–IV). Patients with bone marrow edema were more likely to demonstrate advanced disease compared with those without edema (p = 0.003) (Table 5).

Table 5. Association Between Bone Marrow Edema and Advanced Disease Stage (ARCO III–IV)

Bone Marrow Edema	ARCO I–II n (%)	ARCO III–IV n (%)	Total	p-value
Present	8 (33.3)	16 (80.0)	24	
Absent	16 (66.7)	4 (20.0)	20	0.003
Total	24	20	44	

Chi-square test applied.

DISCUSSION

The present hospital-based observational study evaluated the MRI characteristics of avascular necrosis (AVN) of the femoral head among 44 patients presenting to a tertiary care hospital in North India. The study demonstrated that AVN predominantly affected middle-aged adults, with a clear male preponderance. Hip pain was the most common presenting symptom, while corticosteroid use and chronic alcohol consumption were the leading identifiable risk factors. MRI revealed the double-line sign as the most frequent imaging finding, and most patients presented with ARCO Stage II or III disease. Furthermore, bone marrow edema showed a significant association with advanced-stage disease, suggesting its potential role as a marker of disease progression.

The mean age of patients in the present study was 41.2 years, with the highest frequency observed in the 31–40-year age group. This finding is consistent with previous reports indicating that osteonecrosis of the femoral head primarily affects individuals in the third to fifth decades of life, thereby imposing a substantial socioeconomic burden because of disability during the most productive years of adulthood [1,2]. The predominance of male patients observed in this study is also in agreement with previous epidemiological studies, which have reported higher rates of AVN among men, particularly in association with alcohol use and occupational exposure to risk factors [2,3].

Hip pain emerged as the most common clinical presentation, followed by limping gait and restricted movements of the hip joint. Similar symptom profiles have been reported in earlier studies, where progressive hip pain and functional limitation represented the hallmark manifestations of femoral head osteonecrosis [4,7]. However, clinical findings alone are often nonspecific, highlighting the indispensable role of imaging in establishing an early diagnosis.

Among the identified risk factors, corticosteroid exposure and chronic alcohol intake accounted for a substantial proportion of cases. These observations align with the established literature identifying corticosteroid therapy and excessive alcohol consumption as major non-traumatic causes of AVN [2,3]. Corticosteroids are believed to induce fat-cell hypertrophy, vascular compromise, and increased intraosseous pressure, whereas alcohol-related lipid metabolism abnormalities may contribute to microvascular occlusion and ischemic bone injury. Nevertheless, a considerable proportion of patients in the present study were classified as idiopathic, a finding similarly documented in previous investigations [1].

MRI remains the most sensitive imaging modality for detecting early AVN, and the imaging findings observed in this study support its established diagnostic value. The double-line sign was present in more than three-fourths of patients and represented the most frequent MRI feature. This characteristic finding, typically visualized on T2-weighted images, has been widely described as highly suggestive of osteonecrosis and reflects the interface between necrotic and reparative tissue [7,8]. The high prevalence of this sign in the current study underscores its importance in routine MRI interpretation.

Bone marrow edema and joint effusion were also frequently encountered. Previous studies have demonstrated that marrow edema is often associated with symptomatic disease and may indicate increased mechanical stress, microfractures, or impending collapse of the femoral head [8,11]. The significant association observed between bone marrow edema and advanced ARCO stages in the present study further supports this concept. Similar observations have been reported by investigators who found that edema patterns correlate with disease severity and poorer clinical outcomes [8,12].

The stage distribution in the current study revealed that ARCO Stage II and Stage III lesions constituted the majority of cases, whereas only a small proportion presented during Stage I. This pattern likely reflects delayed healthcare-seeking behavior and referral for advanced imaging after symptom onset. Comparable stage distributions have been reported in studies conducted at tertiary

referral centers, where patients frequently present after radiographic abnormalities have already developed [6,10]. The relatively high proportion of Stage III and Stage IV disease emphasizes the need for increased awareness and earlier MRI evaluation among high-risk individuals.

From a clinical perspective, the findings of this study reinforce the pivotal role of MRI not only in the diagnosis of AVN but also in disease staging and treatment planning. Accurate identification of pre-collapse lesions is essential because joint-preserving procedures such as core decompression are most effective during the early stages, whereas advanced disease often necessitates total hip arthroplasty [9]. Therefore, timely MRI evaluation may contribute to improved patient outcomes and reduced long-term disability.

The strengths of the present study include the use of standardized MRI-based assessment and ARCO staging in a real-world tertiary care setting. The study also provides regional data regarding the MRI spectrum of AVN from North India, where published evidence remains limited.
However, several limitations should be acknowledged. The study was conducted at a single center with a relatively small sample size, which may limit generalizability. The cross-sectional design precluded longitudinal assessment of disease progression and treatment outcomes. Additionally, histopathological confirmation was not available because MRI is considered the accepted non-invasive diagnostic standard in routine clinical practice. Future multicentric studies with larger sample sizes and long-term follow-up are warranted to further evaluate prognostic MRI markers and treatment response.

Overall, the findings of this study support the established role of MRI as the cornerstone imaging modality for the detection, characterization, and staging of avascular necrosis of the femoral head and highlight the importance of early imaging evaluation in patients at risk of developing this disabling condition.

CONCLUSION

Avascular necrosis of the femoral head is an important cause of hip morbidity, particularly among young and middle-aged adults. The present study demonstrated a predominance of male patients, with hip pain being the most common presenting symptom. Corticosteroid use and chronic alcohol consumption were the leading identifiable risk factors. MRI proved to be highly effective in detecting characteristic features of avascular necrosis, with the double-line sign being the most frequently observed imaging finding. Most patients presented in ARCO Stage II or III, indicating that a substantial proportion of cases are diagnosed after disease progression has already occurred.
The significant association between bone marrow edema and advanced-stage disease highlights the prognostic value of MRI in assessing disease severity. MRI not only facilitates early diagnosis but also provides accurate staging that is essential for treatment planning and prediction of outcomes. Early MRI evaluation of high-risk individuals may allow timely intervention and increase the likelihood of joint-preserving management. Further multicentric studies with larger sample sizes and longitudinal follow-up are recommended to validate MRI prognostic markers and optimize management strategies for avascular necrosis of the femoral head.

DECLARATIONS

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Conflict of Interest: The authors declare that there is no conflict of interest.
Informed Consent: Written informed consent was obtained from all participants prior to enrolment in the study.

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