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Radio-Diagnosis

A PROSPECTIVE STUDY ON THE ROLE OF MRI IN THE ASSESSMENT OF AVASCULAR NECROSIS OF THE FEMORAL HEAD

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ABSTRACT **Background:** Avascular necrosis (AVN) of the femoral head is a progressive musculoskeletal disorder that can lead to pain, loss of function, and femoral head collapse. Early diagnosis is crucial, as timely intervention can prevent progression and preserve joint function. Magnetic Resonance Imaging (MRI) is the gold standard for early detection due to its high sensitivity and specificity. **Methodology:** A prospective study was conducted on 60 patients clinically suspected of having AVN of the femoral head. All patients underwent MRI evaluation to detect and stage AVN, assess lesion size and location, and identify associated findings such as joint effusion and bone marrow edema. MRI findings were analyzed according to Mitchell's classification, Steinberg staging, and quadrant involvement. **Results:** Of the 60 patients (81 femoral heads), 52 (86.7%) were males and 8 (13.3%) females, with a mean age of 38.5 ± 13.3 years. AVN was bilateral in 37 patients (61.7%) and unilateral in 23 patients (38.3%). The most common risk factor was alcohol consumption (56%), followed by idiopathic causes (20%). Stage II AVN was most frequent (40%), with the double-line sign observed in 73 femoral heads (90.1%). Bone marrow edema was present in 68 femoral heads (84%), and joint effusion in 57 (70%). Quadrant analysis revealed the anterosuperior compartment was most commonly affected (49%). Mitchell Type B signal (41%) and Steinberg Stage IIIC (31%) were the most prevalent MRI classifications. **Conclusion:** MRI is a highly sensitive and specific modality for the early diagnosis and staging of AVN of the femoral head. It allows accurate detection of lesion location, size, and associated changes, facilitating timely intervention to prevent femoral head collapse and preserve joint function.

KEYWORDS : Avascular Necrosis, Femoral Head, MRI, Steinberg Staging, Double-line Sign

INTRODUCTION

Avascular necrosis (AVN) of the femoral head is defined as the cellular death of bone tissue resulting from an interruption or reduction in its blood supply also known as osteonecrosis. This interruption of blood supply leads to a progressive deterioration of the condition, ultimately causing pain, functional impairment, and collapse of the affected bone.[1] Avascular necrosis (AVN) mostly disturbs the epiphyseal ends of long bones, mainly the femoral and humeral heads; however, smaller bones like scaphoid and talus are frequently involved. AVN most commonly affects individuals in their third to fifth decades of life, with a higher prevalence in males compared to females. Most of patients are asymptomatic but the prevalence is supposed to be markedly higher.[2,3]

The clinical indicators of avascular necrosis (AVN) may vary depending on the bone involved; however, pain remains the predominant and gradually worsening symptom in all cases. The exact pathophysiology of AVN is not completely elucidated, it is generally understood that multiple etiological factors ultimately converge on a common mechanism—compromise of the blood supply to the affected bone or a segment of it.[4] Several risk factors have been related with the progress of avascular necrosis (AVN), including trauma, extended corticosteroid therapy, chronic alcohol consumption, pancreatitis, sickle cell disease, infiltrative disorders, radiotherapy, renal transplantation, Gaucher's disease, gout, and decompression (Caisson) disease.[5] The femoral head is most frequently affected sites, where ischemia leads to osteocyte death and subsequent structural collapse. The disease often begins unilaterally but may progress to involve the contralateral hip, with bilateral involvement reported in up to 72% of cases.[5-7]

Non-invasive imaging modalities in the diagnosis of avascular necrosis (AVN) include plain radiography, magnetic resonance imaging (MRI), computed tomography (CT), skeletal scintigraphy, and single-photon emission computed tomography (SPECT).[8] Early identification of AVN is crucial, as timely intervention with conservative measures such as core decompression can alleviate pain and help preserve normal joint function. MRI is considered the gold standard technique in the early stages of AVN with a sensitivity of more than 99%.[9,10] Plain radiography has limited sensitivity and specificity in detecting early stages (I and II) of avascular necrosis (AVN) and often fails to identify initial pathological changes. However, plain films remain useful for visualizing subtle morphological alterations in the subchondral cortex during later stages of the disease.[9-11]

Bone marrow edema observed on MRI is regarded as an significant indicator of impending femoral head collapse. Early identification of avascular necrosis (AVN) of the femoral head is therefore essential, as timely decompression can prevent disease progression and aid in joint preservation. In patients presenting with clinical features suggestive of AVN but with normal radiographic findings, MRI serves as the preferred imaging modality for accurate diagnosis. Hence, the present prospective study was undertaken to evaluate the role of MRI in the assessment of avascular necrosis of the femoral head.

Aim

The aim of this study is to evaluate the role of magnetic resonance imaging (MRI) in the early diagnosis and assessment of avascular necrosis of the femoral head.

The present prospective observational study was conducted at a tertiary care medical college. The study was approved by the Institutional Ethics Committee, and informed consent was obtained from all participants. The study was conducted in accordance with ICH Good Clinical Practice guidelines. All patients clinically suspected of having AVN of the femoral head and referred to our department for imaging were included in the study based on predefined inclusion and exclusion criteria. Demographic details, including age, gender, weight, and body mass index, were recorded for all patients. A detailed medical history was obtained, with particular emphasis on known risk factors for AVN. Information regarding smoking habits and alcohol consumption was also recorded. A detailed history of trauma, corticosteroid use, or prior radiotherapy was specifically obtained. Potential contraindications to MRI were assessed by specifically inquiring about the presence of cardiac pacemakers, cochlear implants, pregnancy, or claustrophobia. Relevant clinical records and laboratory parameters were reviewed for all patients undergoing MRI evaluation for AVN. All cases were evaluated using the modified Ficat

and Arlet classification, as well as the Sterling and Mitchell classifications. MRI findings, including the presence of bone marrow edema, joint effusion, contour irregularities, reduced joint space, and the double-line sign, were assessed in all cases.

The MRI examination procedure was explained to the patients or their guardians, and written informed consent was obtained. A detailed history of the presenting complaints, past medical history, habits, and presence of ferromagnetic implants (contraindications) was obtained. Statistical analysis was performed using SPSS version 16.0, and Microsoft Office was utilized for the preparation of charts and graphs.

Inclusive Criteria

1. Patients who provided informed consent to participate in the study were included.
2. Clinically suspected cases of AVN included patients presenting with unilateral or bilateral groin, buttock, or thigh pain, hip deformity, or limitation of hip range of motion.
3. Traumatic cases with clinical suspicion of AVN.

Exclusion Criteria

1. Patients unwilling or unable to provide informed consent were excluded from the study.
2. Patients with femur, thigh, or knee pain attributable to causes other than AVN.
3. Patients with contraindications to MRI, such as ferromagnetic implants, cardiac pacemakers, or claustrophobia.

RESULTS

In this study involving 60 patients diagnosed with avascular necrosis of the femoral head, there were 52 (86.67%) males and 8 (13.33%) females, yielding a male-to-female ratio of 1:0.15.

Table 1 - Gender Distribution of the Studied Cases.

Gender	Frequency (n)	Percentage (%)
Male	52	86.67
Female	8	13.33
Total	60	100.00

In the present study of 60 patients with avascular necrosis of the femoral head, the majority (56%) were between 20 and 40 years of age. A total of 16 patients (27%) belonged to the 41–50 years age group, 4 patients (7%) were below 20 years, and 7 patients (12%) were above 50 years of age. The mean age of the study population was 38.5 ± 13.3 years. A statistically significant difference was observed between the mean ages of male and female patients, with females being affected at a relatively younger age ($P < 0.05$).

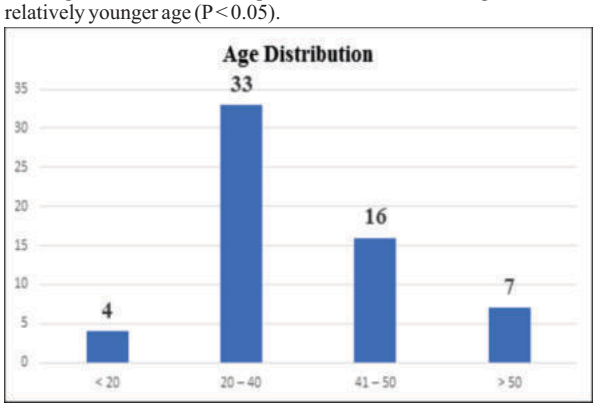

Figure 1 - Age Group of the Studied Cases

In this study of 60 patients, avascular necrosis of the femoral head was bilateral in 37 patients (61.67%) and unilateral in 23 patients (38.33%).

Table 2 - Laterality of Involvement in Affected Cases

Laterality of Involvement	Number of Patients (n = 60)	Percentage (%)
Bilateral	37	61.67
Unilateral	23	38.33
Total	60	100.00

In the present study involving 60 patients with avascular necrosis of the femoral head, the most common associated risk factor was alcohol consumption, observed in 34 patients (56%), followed by idiopathic AVN in 12 patients (20%). Steroid use was identified in 8 patients (14%), while a history of trauma was noted in 10 patients (16%).

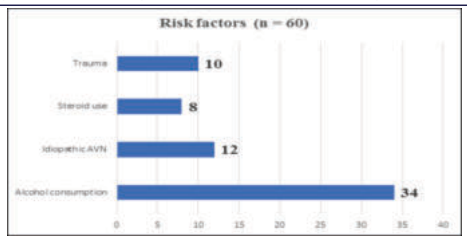

Figure 2 – Distribution of Risk Factor in Affected Cases

In this study of 60 patients with avascular necrosis of the femoral head, Stage I AVN was identified in 1 femoral head (1.7%), Stage II in 24 femoral heads (40%), Stage III in 21 femoral heads (35%), and Stage IV in 14 femoral heads (23.3%).

Table 3 Distribution of Avascular Necrosis (AVN) According to MRI Staging

Stage of AVN	Number of Femoral Heads (n = 60)	Percentage (%)
Stage I	1	1.67
Stage II	24	40.00
Stage III	21	35.00
Stage IV	14	23.33
Total	60	100.00

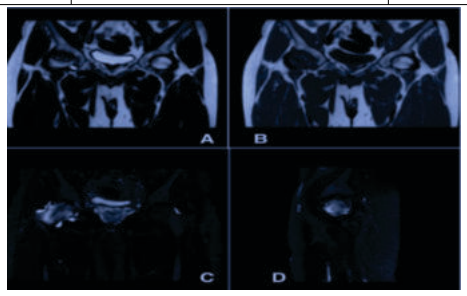

Figure 3 - Coronal T1W and T2W images (A and B) demonstrate a geographic area of altered signal intensity in the right femoral head, appearing hypointense, while corresponding STIR images (C) show hyperintensity in the same region. Partial collapse of the right femoral head with reduction in joint space is evident on the corresponding image (D). These imaging findings are consistent with Stage IV avascular necrosis (AVN) on the right side and Stage I AVN on the left side.

Analysis of MRI findings in the 60 patients included in the study revealed that the most frequent MRI feature was the double-line sign, observed in 73 of 81 femoral heads (90.1%). Other common MRI findings included bone marrow edema in 68 femoral heads (84%), joint effusion in 57 femoral heads (70%), and contour irregularity in 48 femoral heads (59%). Reduced joint space was noted in 20 femoral heads (25%).

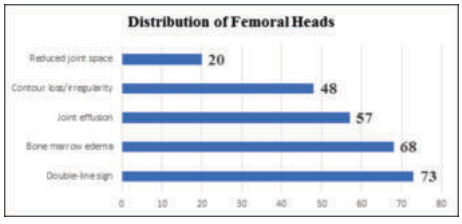

Figure 4 - MRI Findings in Patients with Avascular Necrosis of Femoral Head

Analysis of the age distribution and its correlation with the stage of AVN in 60 patients showed that 12 of 14 femoral heads with Stage IV AVN were in the 41–50 years age group, while 10 of 21 femoral heads with Stage III AVN were in the 21–30 years age group. Among Stage II AVN, 9 of 24 femoral heads were in patients aged 21–30 years. The single femoral head with Stage I AVN was observed in a patient aged 36 years.

Table 4 Association Between Age-group& Staging of AVN

Age Group (Years)	Stage I	Stage II	Stage III	Stage IV
21–30	0	9	10	0
31–40	1	10	8	2

41–50	0	5	3	12
Total	1	24	21	14

In this study of 60 patients involving 81 femoral heads, joint effusion was observed in 57 hips. The highest incidence of effusion was seen in Stage III AVN (25/28 femoral heads, 89.3%) followed by Stage IV AVN (12/14 femoral heads, 85%). Among Stage II AVN cases, 15 of 32 femoral heads (46.9%) showed effusion, whereas the single femoral head with Stage I AVN had no effusion. Bone marrow edema was present in 68 of the 81 affected femoral heads. In Stage II disease, edema was observed in 21 of 32 femoral heads (65.6%). In Stage III disease, edema extending into the neck region was seen in 26 of 28 femoral heads (92.9%). All femoral heads affected by Stage IV AVN (14/14, 100%) demonstrated bone marrow edema, involving the neck and extending into the subtrochanteric region in some cases.

Analysis of the association between joint effusion and bone marrow edema in the 60 patients revealed that 85 % of femoral heads with avascular necrosis demonstrated concurrent joint effusion and bone marrow edema.

In this study of 60 patients involving 81 femoral heads, MRI analysis of quadrant involvement showed that 40 femoral heads (49.38%) had AVN in the anterosuperior compartment, followed by 24 femoral heads (29.63%) with involvement of the anteromedial compartment. Complete femoral head involvement was observed in 14 femoral heads (17.28%), while the anterolateral compartment was affected in 3 femoral heads (3.70%).

Table 5 Quadrant Involvement of Femoral Head in AVN (MRI Findings)

Quadrant Involved	Number of Femoral Heads	Percentage (%)
Anterosuperior	40	49.38
Anteromedial	24	29.63
Complete femoral head	14	17.28
Anterolateral	3	3.70

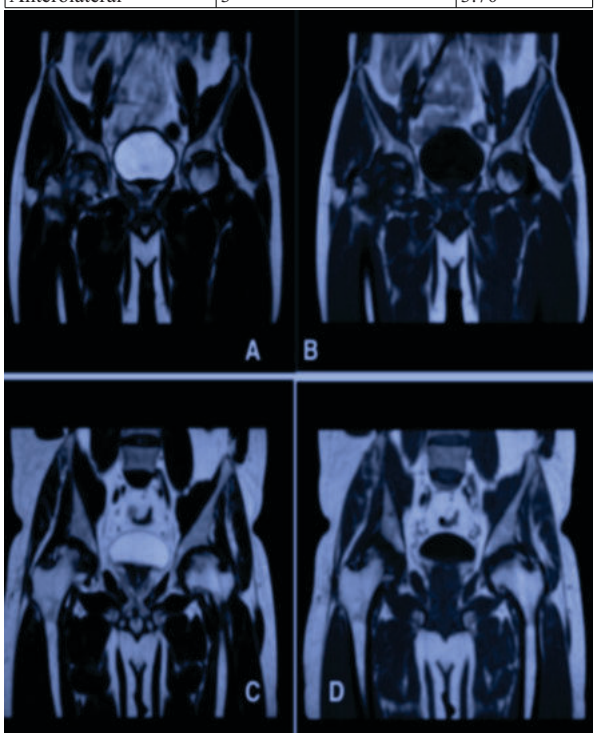

Figure 5 Coronal images (A & B) show hyperintense signal on T2W and T1 within the necrotic foci suggestive of Class B (Blood like).Coronal images (C and D) shows hyper-intense signal on T2W images and hypo intense signal on T1W images within the necrotic foci suggestive of Class C (Fluid like).

In this study based on Mitchell's classification of signal intensity showed that Type B lesions were the most common, observed in 33 femoral heads (41%), followed by Type D lesions in 30 femoral heads (37%). Type C and Type A signals were seen in 13 (16%) and 5 (6%) femoral heads, respectively.

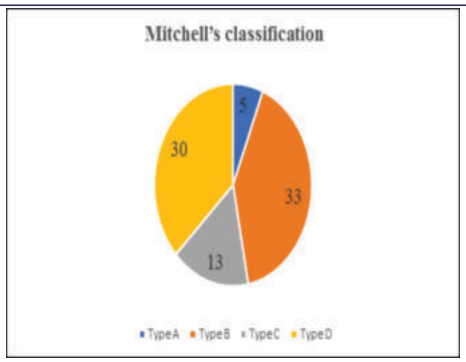

Figure 6 Mitchell's Classification of Signal Intensity in AVN

Analysis based on Steinberg staging revealed that Stage IIIC was the most common, observed in 25 femoral heads (31%), followed by Stage IIC in 19 femoral heads (23%). Stage VI and Stage IIB were seen in 17 (21%) and 10 (12%) femoral heads, respectively.

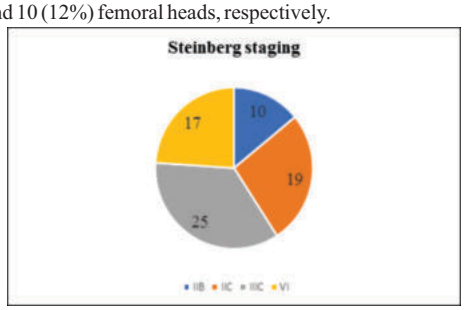

Figure 7 Distribution of Femoral Heads According to Steinberg Staging

DISCUSSION

In the present study of 60 patients with avascular necrosis (AVN) of the femoral head, 52 patients (86.7%) were male and 8 (13.3%) were female, resulting in a male-to-female ratio of 1:0.15, indicating a significantly higher prevalence of AVN in the male population. These findings are consistent with previous studies. Vardhan H et al., in an epidemiological survey of femoral head AVN in the North Indian population, reported a male predominance with a male-to-female ratio of 5:18.[12] Similarly, Zhao DW et al. observed a significantly higher prevalence of AVN in males compared to females, supporting the male predilection noted in the present study.[13]

In the present study of 60 patients with avascular necrosis (AVN) of the femoral head, the majority (56%) were aged between 20 and 40 years. The mean age of the study population was 38.5 ± 13.3 years, with males presenting at a mean age of 38 years and females at a younger mean age of 23 years, showing a statistically significant difference ($P < 0.05$). These findings are comparable to those of Vardan et al., who reported a mean age of 34.7 years (range 14–70 years), with 70.3% of patients in the 20–40 years age group.[12] Similarly, the study by Dr. Mohammad Z S et al. found that the most common age of presentation was between 21–40 years, supporting the observation that AVN predominantly affects young adults.[14]

In the present study of 60 patients with avascular necrosis (AVN) of the femoral head, the condition was bilateral in 37 patients (61.7%) and unilateral in 23 patients (38.3%). The most common associated risk factor was alcohol consumption, observed in 34 patients (56%), followed by idiopathic AVN in 12 patients (20%). Steroid use was identified in 8 patients (14%), and a history of trauma was noted in 10 patients (16%).

These findings are consistent with previous studies. In the study by Dr. Mohammad Z S et al., alcohol was also identified as the most common cause of AVN, observed in 28 patients, with the majority (23/28) aged 31–40 years and having regular drinking habits.[14] Trauma was noted in 8 patients in their study, including 2 with fractures of the neck of the femur, and corticosteroid use was seen in 7 patients. Similarly, Jacobs et al. reported alcohol as the most common risk factor in 39% of cases.[15] In contrast, Kamal D et al. found smoking to be the predominant risk factor, accounting for 36.9% of cases. These comparisons highlight alcohol consumption as a major contributory factor for AVN, consistent with the findings of the present study.[16]

In the present study of 60 patients with avascular necrosis (AVN) of the femoral head, Stage I AVN was observed in 1 femoral head (1.7%), Stage II in 24 femoral heads (40%), Stage III in 21 femoral heads (35%), and Stage IV in 14 femoral heads (23.3%). MRI analysis revealed that the most frequent finding was the double-line sign, seen in 73 of 81 femoral heads (90.1%). Other common MRI features included bone marrow edema in 68 femoral heads (84%), joint effusion in 57 femoral heads (70%), contour irregularity in 48 femoral heads (59%), and reduced joint space in 20 femoral heads (25%).

Correlation of AVN stage with age showed that 12 of 14 femoral heads with Stage IV AVN were in the 41–50 years age group, while 10 of 21 femoral heads with Stage III AVN were in the 21–30 years age group. Among Stage II AVN cases, 9 of 24 femoral heads were in patients aged 21–30 years. The single femoral head with Stage I AVN was observed in a 36-year-old patient.

These findings are comparable to those reported by Dr. Mohammad Z S et al., who noted that in Stage II disease, most femoral heads were classified as Class C (16 patients), followed by Class B (14 patients) and Class A (3 patients).[14] In Stage III disease, the majority of femoral heads had >30% involvement. Among Stage IV cases, 12 of 20 patients exhibited advanced degenerative changes and osteoarthritis.

In the present study, 9 hips had <30% femoral head involvement, 40 hips had 30–50% involvement, and 34 hips had >50% involvement. Mild contour loss was observed in hips with 30–50% involvement, whereas partial to complete collapse occurred in those with >50% involvement. Among Stage IV hips, 6 showed partial collapse, 2 had acetabular involvement, and 12 demonstrated secondary degenerative changes.

These observations are consistent with the findings of Nam K. W et al., who reported that asymptomatic AVN lesions involving <30% of the femoral head carry a low risk of collapse, lesions involving 30–50% carry a moderate risk, and lesions with >50% involvement carry a high risk of collapse.[17] Similarly, Betral et al. concluded that the likelihood of femoral head collapse is directly proportional to the size of the lesion, with larger areas exhibiting a higher risk of collapse.[18] The present study corroborates previous evidence that the extent of femoral head involvement is a critical predictor of disease progression and structural collapse.

In the present study of 60 patients involving 81 femoral heads, joint effusion was observed in 57 hips, with the highest incidence in Stage III AVN (25/28 femoral heads, 89.3%) followed by Stage IV AVN (12/14 femoral heads, 85%). Among Stage II AVN cases, 15 of 32 femoral heads (46.9%) demonstrated effusion, whereas the single femoral head with Stage I AVN had no effusion. Bone marrow edema was present in 68 of the 81 affected femoral heads. Specifically, in Stage II disease, edema was noted in 21 of 32 femoral heads (65.6%), in Stage III disease, edema extending into the neck region was seen in 26 of 28 femoral heads (92.9%), and all Stage IV femoral heads (14/14, 100%) demonstrated bone marrow edema, extending into the subtrochanteric region in some cases. Analysis of the association between joint effusion and bone marrow edema revealed that 85% of femoral heads showed concurrent findings, highlighting a strong correlation between these MRI features in AVN.

MRI analysis of quadrant involvement showed that 40 femoral heads (49.4%) had AVN in the anterosuperior compartment, 24 femoral heads (29.6%) in the anteromedial compartment, 14 femoral heads (17.3%) had complete femoral head involvement, and 3 femoral heads (3.7%) involved the anterolateral compartment. These findings align with Dr. Mohammad Z S et al., who reported anterosuperior involvement in 53% of cases across all stages and anteromedial involvement in 32% of cases.[14] Similarly, Gabriel H et al. highlighted the specificity of lesions along the anterosuperior aspect on MRI, and T. Nishi et al. emphasized that lesion size and location, particularly in the anterosuperior region, are prognostic indicators for femoral head collapse.[20]

In the present study, analysis of MRI findings using Mitchell's classification of signal intensity demonstrated that Type B lesions were the most frequently observed, seen in 33 femoral heads (41%), followed closely by Type D lesions in 30 femoral heads (37%). Type C and Type A lesions were less common, seen in 13 (16%) and 5 (6%) femoral heads, respectively. This distribution suggests that a majority of patients presented with intermediate to advanced changes on MRI, consistent with progressive avascular necrosis, as Type B and D signals typically indicate evolving necrotic changes and reparative processes within the femoral head. These findings are in line with previous studies, which reported a higher prevalence of Type B and D lesions in patients with clinically significant AVN, reinforcing the utility of Mitchell's classification in assessing the stage and severity of disease.[14]

When the study population was analyzed using Steinberg staging, Stage IIIC was the most common, observed in 25 femoral heads (31%), followed by Stage IIC in 19 femoral heads (23%). Stage VI and Stage IIB were seen in 17 (21%) and 10 (12%) femoral heads, respectively. The predominance of Stage IIIC reflects that a significant proportion of patients in this cohort presented with moderate to advanced disease, which correlates with the MRI findings of extensive necrotic involvement in Type B and D lesions. This pattern emphasizes the progressive nature of AVN, with increasing structural compromise as the disease advances through Steinberg stages.

Overall, the combined assessment using Mitchell's signal intensity classification and Steinberg staging demonstrates that most patients in the present study exhibited intermediate to advanced AVN, with a higher likelihood of femoral head involvement and potential progression to collapse. These findings highlight the importance of early detection using MRI to identify subtle signal changes, guide timely intervention, and potentially prevent progression to later stages associated with structural compromise and secondary osteoarthritis.

CONCLUSION

The present study conclude that Avascular necrosis of the femoral head is an important cause of musculoskeletal disability, and early diagnosis is critical for achieving optimal clinical outcomes. This study highlights that MRI is the investigation of choice in patients with clinical suspicion of AVN, offering high sensitivity and specificity. MRI not only facilitates early detection of lesions but also allows accurate staging, which is essential for guiding timely intervention and improving patient prognosis.

Conflict of Interest: None

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