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Role of 3T MRI to Evaluate Avascular Necrosis (AVN) of the Femoral Head

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Abstract

Avascular necrosis (AVN), also referred to as osteonecrosis, is a pathological condition characterized by the death of bone tissue resulting from an inadequate blood supply. A range of factors can compromise vascular flow to bone, leading to progressive structural deterioration. This deterioration typically causes chronic pain, reduced joint function, and, ultimately, collapse of the affected bone. Although the precise mechanisms underlying AVN are not yet fully elucidated, it is clear that multiple factors can disrupt the bone's vascular supply, setting this disease process in motion [1].

Numerous risk factors have been identified in the development of AVN. These include prolonged corticosteroid use, excessive alcohol intake, and immunosuppressive therapies. Traumatic injuries—such as femoral head or neck fractures and hip dislocations—are also important contributors. Additionally, inflammatory diseases like pancreatitis, connective tissue disorders, and rheumatoid arthritis increase risk. Exposure to radiation therapy and hematologic disorders—including sickle cell anemia, hemophilia, and polycythemia vera—are well-established causes. Metabolic and endocrine conditions such as pregnancy, diabetes mellitus, Cushing's syndrome, and Gaucher's disease further elevate susceptibility. Despite their diversity, these factors share the common pathway of impairing bone perfusion, thereby initiating necrosis and disease progression.

Keywords: NIL

Introduction

Avascular necrosis (AVN), also referred to as osteonecrosis, is a pathological condition characterized by the death of bone tissue resulting from an inadequate blood supply. A range of factors can compromise vascular flow to bone, leading to progressive structural deterioration. This deterioration typically causes chronic pain, reduced joint function, and, ultimately, collapse of the affected bone. Although the precise mechanisms underlying AVN are not yet fully elucidated, it is clear that multiple factors can disrupt the bone's vascular supply, setting this disease process in motion [1].

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Estimating the incidence of AVN remains challenging due to underdiagnosis and variations in reporting. Nonetheless, it is estimated that approximately 2,500 new cases occur annually in Japan, while in the United States, annual cases are estimated between 10,000 and 30,000 [3].

A solid understanding of hip pathology requires detailed knowledge of hip anatomy, including the bony framework, articular hyaline cartilage, the fibrocartilaginous acetabular labrum, the joint capsule, associated ligaments, and surrounding tendons and bursae [4].

Early detection of AVN in the femoral head is essential to allow conservative management strategies that can relieve pain and help preserve joint function. However, once a subchondral fracture develops, surgical intervention—often total joint replacement—becomes necessary, though this carries a higher risk of morbidity [5].

Initial diagnostic evaluation for suspected AVN usually begins with plain radiography of the hip. However, radiographs often appear normal in early stages. Magnetic resonance imaging (MRI) has become the gold standard for diagnosis, offering superior sensitivity (over 99%) compared to computed tomography (CT) and bone scans. MRI accurately stages disease, delineates lesion size, and assesses extent of involvement. Its advantages include non-invasiveness, absence of ionizing radiation, high soft-tissue contrast, and multiplanar imaging capability, making it invaluable for early detection and monitoring of AVN [6].

In 1964, Ficat and Arlet proposed the first widely used classification system for AVN of the femoral head, which predated modern MRI imaging. This system aimed to provide prognostic information and aid in treatment planning. Over time, at least 16 classification systems have been described. Among these, the Ficat classification remains the most commonly used (63% of cases), followed by the University of Pennsylvania system (20%), the Association Research Circulation Osseous (ARCO) system (12%), and the Japanese Orthopaedic Association system (5%) [7].

MRI plays a critical role in the precise identification, localization, and characterization of hip disorders. For AVN specifically, MRI is the most reliable imaging modality, demonstrating both sensitivity and specificity exceeding 99% [8]. The primary value of MRI lies in its ability to detect AVN in symptomatic patients before radiographic changes occur, and to screen high-risk asymptomatic individuals or the contralateral hip in patients with known disease.

This study seeks to leverage the advanced imaging capabilities of 3 Tesla MRI (3T MRI) to evaluate patients with clinically suspected AVN of the hip. The aim is to provide detailed imaging characterization, accurate staging using multiplanar and cross-sectional techniques, and ultimately to support timely and targeted management. Conducting this research at a tertiary care center ensures access to state-of-the-art imaging technology and specialized expertise, which together enable high diagnostic accuracy, comprehensive care, and improved patient outcomes through early intervention.

Aims And Objectives

Aim:

To evaluate the diagnostic performance of 3 Tesla Magnetic Resonance Imaging in the detection, staging, and clinical assessment of avascular necrosis (AVN) of the femoral head.

Objectives:

1. To assess the role of 3T MRI in detecting early and advanced stages of AVN in patients presenting with hip pain.
2. To characterize and describe the imaging features of AVN on 3T MRI using standardized classification systems.
3. To evaluate the multiplanar and high-resolution imaging capabilities of 3T MRI in the detailed assessment of femoral head pathology.
4. To correlate MRI-based staging of AVN with clinical parameters, including pain severity (Numeric Rating Scale) and functional status (Harris Hip Score).

Advantages Of 3 Tesla Mri

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The latest generation of 3.0-T MRI scanners now incorporates optimized coils and sequences specifically designed for musculoskeletal imaging. Although experience with these systems is still developing, it appears probable that the enhanced capabilities offered by these advancements will allow for greater realization of the benefits of higher field strength in clinical practice compared to just a year ago. 3.0 Tesla will likely focus on shorter examination times and increased patient throughput (13).

MRI systems operating at 3.0 Tesla are specifically utilized in neuroradiology applications (14). Numerous studies have highlighted the benefits of employing higher magnetic field strengths in various areas of MRI imaging. Operating at 3.0 Tesla enables enhanced spatial resolution imaging of the pelvis, which proves valuable in the assessment of gynecological tumors (15). Additionally, promising outcomes have been observed in evaluating diffuse lung diseases (16), and there is indication suggesting improved diagnostic capabilities in cardiac imaging at this field strength.Studies focusing on musculoskeletal disorders have consistently shown enhanced imaging quality and efficiency at 3.0 Tesla, along with initial evidence suggesting an accompanying improvement in diagnostic precision (16).

Materials And Methods

Study Setting: Tertiary Care Centre

Study Design: Prospective observational study

Study Period: 2 years

Selection Criteria

Inclusion Criteria:

1. All clinically suspected cases of AVN of hip with bilateral and unilateral hip pain.
2. All patients with incidentally diagnosed with AVN of hip joints.
3. Patients of all age groups and both sexes.
4. Traumatic cases clinically suspected to have AVN.

Exclusion Criteria:

1. Patient having history of claustrophobia.
2. Patient having history of metallic implants insertion, cardiac pacemakers and metallic foreign body in situ
3. Patients not giving the consent for study.
4. Patient who are physically inactive.
5. Pregnant women

Sample Size: 40

Study Procedure

Patient Enrolment:

Participants were recruited from a tertiary care academic research institute. The inclusion criteria comprised individuals with clinically suspected avascular necrosis (AVN) of the hip joint. Informed consent was obtained from all participants or their guardians before enrollment.

Clinical History and Assessment:

A thorough clinical evaluation was conducted for each participant, which included a detailed medical history and physical examination focused on symptoms indicative of AVN, such as pain, reduced mobility, and any history of trauma or corticosteroid use.

Imaging Procedure

Equipment used: SEIMENS MAGNETOM SKYRA 3T MRI.

MRI Sequence used:

Imaging Plane	Acquisition Scheme	Slice Thickness (mm)	TR	TE	Matrix	gap
Cor	T2 STIR	3.0mm	4970	57	320 x240	0.5mm

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Cor	T1 TSE	3.0mm	6250	10	320x260	0.5mm
Axial	PDFS	3.0mm	2500	29	320x260	0.5mm
Cor	PDFS	3.0mm	2500	29	320x260	0.5mm
Axial	T2 TSE	3.0mm	3200	96	320x220	0.5mm
Cor	T2 TSE	3.0 mm	3200	96	320x220	0.5mm
Sag	PDFS	3.0 mm	2400	28	260x320	0.5mm

Classification and Staging:

AVN was staged using the Ficat and Arlet classification and Michell's classification based on MRI findings:

Ficat and Arlet classification: Focused on radiological changes, femoral head collapse, and joint space narrowing.

Michell's classification: Categorized lesions into Class A (fat-like), Class B (blood-like), Class C (fluid-like), and Class D (fibrous-like).

Discussion

The role of 3 Tesla Magnetic Resonance Imaging (3T MRI) in evaluating avascular necrosis (AVN) of the hip joint has demonstrated significant advancements in diagnostic accuracy and detailed imaging capabilities. In this study, we evaluated 65 hip joints from 40 patients with clinically suspected AVN using 3T MRI to ascertain its efficacy in identifying and staging the disease, as well as its complications. Our findings highlight the superiority of 3T MRI in detecting early AVN changes, which are often not visible on conventional radiographs. The high spatial resolution and multi-planar imaging capabilities of 3T MRI allowed for precise assessment of the necrotic areas, cartilage condition, and any associated joint effusions or bone marrow edema. Moreover, the correlation between MRI findings and clinical presentations provided a comprehensive understanding of the disease progression and its impact on patient symptoms. Recent studies have demonstrated the utility of MRI in diagnosing AVN with high sensitivity and specificity, making it a preferred modality for early detection (17). The multi-planar imaging capabilities and superior contrast resolution of 3T MRI provide detailed visualization of bone and soft tissue structures, which is crucial for accurate staging and treatment planning (17) (18). The use of MRI in clinical practice has been shown to significantly impact the management of AVN, allowing for earlier and more effective interventions (19) (20). This study underscores the critical role of 3T MRI in the early detection, accurate staging, and management planning for patients with AVN of the hip joint, emphasizing its importance in improving patient outcomes through timely and targeted therapeutic interventions.

Gender Based Prevalence

The present study demonstrates a male predominance in the incidence of avascular necrosis (AVN) of the hip joint, with 72.5% of the cases being male and 27.5% female, resulting in a male-to-female ratio of 1:0.38. These findings are consistent with several past studies,

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indicating a general trend towards higher male prevalence in AVN cases.

For instance, the study by El-Shourbagy KH. et al. (21) reported a similar male predominance with 56% of the cases being male and 44% female, yielding a male-to-female ratio of 1.3:1. This is closely mirrored by the study conducted by NVP V. et al. (22), which also reported a male prevalence of 56.7% compared to 43.3% female, resulting in a ratio of 1.3:1.

The study by Chander R. et al. (23) reported a male predominance of 76% compared to 24% female, although the exact ratio was not specified, this further supports the trend of higher male incidence. Similarly, Saleem MZ et al. (24) found a significantly higher male prevalence with 86% of the cases being male and only 14% female, resulting in a ratio of 1.0:0.16, the highest male predominance among the compared studies.

In contrast, Osman NM. et al. (25) presented an unusual deviation from this trend with a female predominance where 68.3% of the cases were female and only 31.7% male. Bollipo JP. et al. (2018) reported a male-to-female ratio of 74% to 26%, aligning with the majority trend of male predominance.

The higher male prevalence of avascular necrosis (AVN) of the hip joint observed in this and other studies may be attributed to various factors, including hormonal influences, lifestyle differences, and genetic predispositions. Hormonal factors, such as the protective effect of oestrogen on bone health, may contribute to the lower incidence of AVN in females, particularly postmenopausal women (26). Lifestyle factors, including higher rates of alcohol consumption and smoking among males, are well-documented risk factors for AVN and may account for the gender disparity. Additionally, genetic predispositions, with specific polymorphisms associated with increased susceptibility to AVN, may also play a role and differ between males and females (27).

Age Based Prevalence

The present study reports an average age of 35.7±15.3 years, with participants up to 20 years old comprising 20.0%, those aged 21 to 30 years making up 22.5%, and the 31 to 40 years age group also representing 22.5%. The 41 to 50 years age group accounted for 15.0%, while those above 50 years constituted 20.0% of the participants. This distribution indicates a concentration in the younger to middle-aged categories. Comparatively, studies like El-Shourbagy KH. et al. (31) reported an older average age of 54.94 ± 10.52 years, while Chander et al. (28) and Gehlot PS et al. (29) identified the 31 to 45 years and 21 to 40 years age groups as most prevalent, respectively. Saleem MZ et al. (30) found an average age of 38.48 ± 13.28 years, and Osman NM. et al. (32) also focused on the 20-40 years age group. Bollipo JP. et al. (33) reported two prevalent age groups: 51-60 years and 21-30 years.

The high prevalence of AVN in middle age can be attributed to several factors. This age group is often exposed to lifestyle-related risks such as alcohol consumption, corticosteroid use, and trauma, which are significant contributors to AVN development. Additionally, genetic predispositions and metabolic conditions prevalent in this age range can increase susceptibility. The combination of these factors leads to a higher incidence of AVN among middle-aged individuals.

Laterality in AVN Cases

The present study reports that 62.5% of the cases were bilateral, while 37.5% were unilateral, with the right side being affected in 27.5% of unilateral cases and the left side in 10% (Table and Graph No 2). These findings are consistent with several other studies, which also observed a higher prevalence of bilateral AVN. For instance, Chagdal S. et al. (32) and Pawar-Dahiphale A. et al. (99) both reported 62.5% of cases being bilateral. Similarly, Saleem MZ et al. (25) found 62% of cases to be bilateral, and Osman NM. et al. (20) reported a slightly lower percentage of 53.3%. In contrast, El-Shourbagy KH. et al. (15) observed a lower incidence of bilateral cases at 35.4%, with a higher incidence of unilateral cases at 64.6%.

Bilateral AVN of the hip is more common compared to unilateral AVN due to several factors. One significant factor is the systemic nature of the risk factors associated with AVN, such as corticosteroid use, alcohol consumption, and certain medical conditions like sickle cell disease and lupus. These factors tend to affect both hips simultaneously rather than just one. Additionally, the vascular supply to the femoral head is similar on both sides, and any condition that compromises blood flow is likely to impact both hips. Furthermore, the biomechanical stresses and activities that contribute to AVN are typically symmetrical, affecting both hips equally. The cumulative effect of these systemic and biomechanical factors results in a higher prevalence of bilateral AVN (14,15).

MRI Findings in the Hip AVN

The present study's MRI findings of Hip AVN (Avascular Necrosis) show several similarities with past studies. Notably, the prevalence of bone marrow edema is a consistent finding, observed in 93.8% of cases in the present study and similarly high in studies by Saleem MZ et al. (83.95%) (12), Osman NM. et al. (60%) (14), and Bollipo JP. et al. (72%) (15). The double-line sign, a hallmark of AVN, was identified in 86.2% of cases in the present study, comparable to 90.12% in Saleem MZ et al. (102), 80% in Osman NM. et al. (104), and 81% in Bollipo JP. et al. (15) Additionally, joint effusion was noted in 87.7% of cases in the present study, aligning with findings from El-Shourbagy KH. et al. (75%) (9) and Saleem MZ et al. (70.37%) (12).

However, there are notable differences as well. The present study reported reduced joint space in 61.5% of cases (Table No 10 and graph 09), which is higher compared to 24.69% reported by Saleem MZ et al. (102) Contour loss was observed in 66.2% of the present study's cases (Table No 10 and graph 09), while Saleem MZ et al. (102) reported a lower percentage of 59.26%. Additionally, Chagdal S. et al. (95) and Pawar-Dahiphale A. et al. (99) reported 100% prevalence of focal subchondral signal abnormalities, which were not as prominently highlighted in the present study.

The commonalities in findings across different studies can be attributed to the pathophysiological characteristics of AVN, which typically include bone marrow edema and the double-line sign detectable by MRI. These features are fundamental indicators of the disease process and are reliably identified by advanced imaging techniques. Differences in findings, such as the varying prevalence of reduced joint space and contour loss, may be due to differences in the stages of AVN at which patients are evaluated, variations in the study populations, or the criteria used for diagnosis and staging. Additionally, slight differences in MRI technology, interpretation, and the expertise of radiologists might contribute to these discrepancies (14).

X Ray findings of Hip AVN and comparison to MRI.

The present study's X-ray findings of Hip AVN (Avascular Necrosis) are categorized into four stages, reflecting the progression of the disease. In Stage I, which accounts for 9.2% of cases, X-rays appear normal with only early changes, making it difficult to detect AVN at this initial stage Stage II, observed in 29.2% of cases, reveals sclerosis or cysts visible in X-rays, without evidence of femoral head collapse Stage III is characterized by the presence of a subchondral fracture and the "crescent sign," marking the beginning of femoral head collapse, and is seen in 44.6% of cases Stage IV, which includes 16.9% of cases, shows complete collapse of the femoral head with loss of its round shape, joint space narrowing, and acetabular changes.

In comparison, Chander R. et al. (10) reported X-ray findings where osteoporosis was present in 100% of their cases. Sclerosis and altered morphology were each observed in 42.8% of cases, while subchondral cysts were noted in 57.1%, and the crescent sign/subchondral lucency was seen in 42.8%. These findings indicate that Chander R. et al. (10) focused more on specific structural changes identifiable by X-rays, such as osteoporosis and subchondral cysts, whereas the present study categorizes findings into progressive stages, providing a broader overview of the disease development.

The MRI findings in the present study clearly demonstrate its superiority over X-ray in diagnosing and evaluating avascular necrosis (AVN) of the hip. MRI is able to detect early indicators of AVN such as bone marrow edema (93.8%) and joint effusion (87.7%), which are not visible on X-rays. Additionally, the double-line sign, identified in 86.2% of MRI cases, is a specific feature crucial for diagnosis that X-rays cannot reveal. MRI also provides detailed assessments of joint space narrowing and contour loss, offering a more accurate staging of the disease. In contrast, X-rays often miss early-stage AVN, with normal X-rays observed in 9.2% of early-stage cases, and typically only detect later changes such as sclerosis, cysts, and femoral head collapse. Therefore, MRI's ability to identify both early and specific signs of AVN makes it a superior imaging modality compared to X-ray.

Mitchell's Classification of Hip AVN Cases

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The present study, using Mitchell's Classification, found that the majority of cases (46.2%) were classified as Class D (fibrous-like), followed by Class C (fluid-like) at 26.2%, Class A (fat-like) at 15.4%, and Class B (blood-like) at 12.3% findings highlight a significant presence of advanced stages of AVN in the studied population.

In comparison, Chagdal S. et al. (95) reported that 38% of cases were in Stage C, 25% in Stage B, 19% in Stage A, and 12% in Stage D. Pawar-Dahiphale A. et al. (99) similarly found that 37.5% of cases were in Stage C, 25% in Stage B, and 18.75% in both Stages A and D. Saleem MZ et al. (12) reported a slightly different distribution with 40.74% in Stage B, 37.04% in Stage D, 16.05% in Stage C, and only 6.17% in Stage A.

These differences may be attributed to variations in the study populations, diagnostic criteria, and the stages at which patients were evaluated. The present study's higher prevalence of Class D (fibrous-like) cases indicates a more advanced disease stage, potentially reflecting a population with longer disease duration and progression to severe stage.

Ficat and Arlet classification of Hip AVN Cases

The present study's findings using the Ficat and Arlet classification indicate that the majority of cases are in Stage III (61.5%), followed by Stage IV (18.5%), Stage II (16.9%), and Stage I (3.1%). This suggests a significant number of patients present with advanced stages of AVN.

Comparatively, Chagdal S. et al. (95) reported a similar distribution with the highest percentage in Stage III (44%), followed by Stage II (30%), and equal distribution in Stage I and IV (13%). Pawar-Dahiphale A. et al. (99) also found the highest prevalence in Stage III (43.75%), followed by Stage II (31.25%), and equal distribution in Stage I and IV (12.5%). Saleem MZ et al. (102) showed a slightly different pattern with the highest percentage in Stage II (39.50%), followed by Stage III (34.56%), Stage IV (24.69%), and the lowest in Stage I (1.23%).

The common finding across these studies is the high prevalence of advanced stages (III and IV) of AVN, which indicates that many patients are diagnosed when the disease has already significantly progressed. This consistency highlights the importance of early detection and intervention to prevent the progression to these advanced stages.

The present study shows a strong concordance between the Ficat and Arlet classification and the Mitchell classification in evaluating AVN Early stages (Stage I at 3.1% and Stage II at 16.9% in Ficat and Arlet, and Classes A at 15.4% and B at 12.3% in Mitchell) correspond well, highlighting initial changes with potential reversibility. Intermediate stages (Stage III at 61.5% in Ficat and Arlet, and Class C at 26.2% in Mitchell) both indicate significant disease progression with subchondral fractures. Advanced stages (Stage IV at 18.5% in Ficat and Arlet, and Class D at 46.2% in Mitchell) correlate with substantial femoral head collapse and joint space narrowing. Both systems effectively capture the disease progression, though Ficat and Arlet focus on radiographic changes while Mitchell emphasizes tissue characteristics, supporting their combined use for comprehensive AVN assessment.

Location of Femur Head

In the present study, the most common location of AVN in the femur head was the antero-superior compartment, observed in 64.6% of cases. This was followed by the antero-medial compartment at 26.2%, antero-lateral and complete involvement both at 3.1%, and antero-superior and medial, as well as supero-lateral compartments each at 1.5%.

Comparatively, Saleem MZ et al. (2019) found the antero-superior compartment to be the most commonly affected area, present in 51.85% of cases, followed by the antero-medial compartment at 30.86%, complete femoral head involvement at 16.05%, and the antero-lateral compartment at 1.23%.

Both studies highlighted the antero-superior compartment as the primary site of AVN, reflecting its vulnerability due to weight-bearing and vascular supply characteristics.

Risk Factors Associated with Hip AVN

The present study's findings on risk factors for avascular necrosis (AVN) show both similarities and variations when compared to previous studies. Trauma was identified as a leading risk factor in 32.5% of the present study's participants. This is higher compared to the 16% reported by Saleem MZ et al. (12). Trauma-related AVN often results from femoral neck fractures

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or hip dislocations, which can severely disrupt blood supply to the bone.

Idiopathic cases accounted for 27.5% in the present study, compared to 20% in Saleem MZ et al. (12) This higher prevalence may be due to different diagnostic criteria and patient populations. Idiopathic AVN is challenging to diagnose and often requires exclusion of other known causes (15).

Alcohol consumption was a risk factor in 15% of the present study, significantly lower than the 56% reported by Saleem MZ et al. (2019) (12). This stark contrast might reflect regional differences in alcohol consumption or demographic variations among study populations. Excessive alcohol use is known to contribute to fatty deposits in blood vessels, leading to AVN (15).

Corticosteroid use was noted in 5% of cases in the present study., compared to 40% reported by Saleem MZ et al. (12). Corticosteroids are a well-documented risk factor for AVN, potentially due to their effects on lipid metabolism and blood flow (15) (16). The variation might be due to different medical practices or patient populations.

Sickle cell disease was identified as a risk factor in 15% of the present study, a condition not reported in Saleem MZ et al. (12). Sickle cell disease can lead to repeated episodes of blood vessel occlusion, increasing the risk for AVN.

Other minor contributing factors included combined trauma and alcohol use (2.5%) and infection (2.5%). These factors, while less common, still play a significant role in the multifactorial nature of AVN.

Overall, the present study emphasizes the diverse etiologies of AVN, highlighting the importance of considering a broad range of risk factors. Further research is essential to understand the interplay of these factors fully and develop targeted prevention and treatment strategies for AVN.

Conclusion

The present study underscores the pivotal role of 3T MRI in evaluating clinically suspected cases of avascular necrosis (AVN) of the hip joint. 3T MRI was found to be highly effective in detecting complications such as joint effusion, bone marrow edema, and contour loss, which are critical for early diagnosis and intervention. The detailed imaging features provided by 3T MRI, including the prominent "double line sign," were instrumental in diagnosing and staging AVN accurately. Utilizing the Ficat and Arlet classification alongside Michell's classification, the study demonstrated the precision of 3T MRI in determining the extent and severity of AVN.

In conclusion, 3T MRI is an indispensable tool in the diagnosis and management of AVN, offering comprehensive views and detailed assessments that enhance diagnostic accuracy and inform treatment strategies. Its advanced multi-planar imaging capabilities and cross-sectional techniques provide invaluable insights into the condition of the hip joint, underscoring its importance in clinical practice. The findings highlight the necessity of incorporating advanced MRI technology in tertiary care academic research settings to improve patient outcomes in AVN and other musculoskeletal disorders.

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