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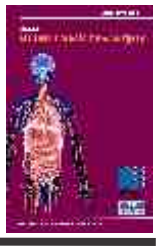

Research Article

Section: Radiodiagnosis

Radiological Approach for Early Diagnosis of Diabetic Foot Disease

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HIGHLIGHTS

- Early imaging crucial for diabetic foot
- MRI detects soft tissue complications early
- X-ray useful for bone involvement evaluation.
- Doppler studies assess vascular insufficiency.
- Timely diagnosis prevents severe complications.

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ABSTRACT

Introduction: Diabetic foot disease (DFD) is a serious complication of diabetes mellitus, leading to ulcers, infections, and amputations. Early detection is critical to prevent severe morbidity. This study investigates the effectiveness of various radiological modalities in diagnosing DFD at its early stages, particularly before ulcer formation. **Aim and Objective:** To diagnose diabetic foot disease in its early stage and evaluate the role of different radiological modalities especially ultrasound and MRI in its early detection and monitoring, thereby enabling timely management and prevention of progression to advanced disease. **Materials and Methods:** This prospective observational study was conducted on 96 diabetic patients with suspected early foot complications. All patients underwent ultrasound with Doppler assessment. MRI was performed in 24% of patients based on clinical indication. Imaging findings were correlated with clinical data and monitored over time. Ethical clearance and informed consent were obtained. **Results:**The study population consisted predominantly of males (58.33%) aged 46–60 years 38.54%). Symptomatic presentations were more common (66.67%). Atherosclerosis was the most frequent risk factor (66%), followed by poor glycemic control (19.61%). ltrasound detected abnormalities in 73 of 96 cases, yielding a 76% diagnostic capability. MRI identified changes in 14 of 23 patients, yielding a 60% diagnostic capability. Ultrasound was effective in identifying vascular and soft tissue changes, while MRI provided detailed soft tissue and bone marrow evaluation in complex cases. **Conclusion:** Ultrasound is a valuable first-line imaging modality in early DFD diagnosis. MRI serves as an essential adjunct in selected cases. Integrating both into diabetic foot evaluation protocols enhances early detection and improves patient outcomes.

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INTRODUCTION

Diabetes mellitus is a chronic metabolic disorder that arises due to a deficiency in insulin production, impaired insulin action, or a combination of both, resulting in persistent hyperglycemia. It significantly impacts multiple organ systems, including the eyes, kidneys, nerves, and cardiovascular structures, and is one of the leading causes of morbidity and mortality worldwide (1). Over the past few decades, the prevalence of diabetes has risen dramatically, with the International Diabetes Federation estimating that more than 536 million adults aged 20 to 79 years were living with diabetes in 2021. This figure is projected to exceed 783 million by 2045 (2). In India, the burden of diabetes is particularly high, with more than 77 million affected individuals, placing it second globally after China. Alarmingly, over 12 million Indian diabetics are above the age of 65, and this number is anticipated to double by 2045. Diabetes contributes to an estimated 2% of all deaths in India, making it a critical public health issue(3).

Among the numerous complications associated with diabetes mellitus, diabetic foot disease represents one of the most severe and life-altering manifestations. It encompasses a range of foot pathologies including ulcers, infections, deformities, and gangrene, often culminating in partial or complete lower limb amputations (4). Epidemiological data suggest that approximately one-fifth to one-third of diabetic patients are at risk of developing foot ulcers during their lifetime. Once an ulcer develops, the risk of subsequent infection, hospitalization, or amputation increases signifi - cantly (5). Studies in India indicate that diabetic foot complications are present in nearly 4.5% of newly diagnosed type 2 diabetic patients, with nearly half being neuropathic, and the remainder divided between ischemic and neuroischemic types. Notably, around 20% of patients with diabetic foot ulcers ultimately require amputation, and about 10% succumb within a year of the initial diagnosis(6).

The development of diabetic foot disease is multifactorial and arises from a combination of peripheral neuropathy, peripheral arterial disease, and compromised immune function. Peripheral neuropathy, especially distal symmetrical polyneuropathy, affects up to half of individuals with long-standing diabetes. It leads to diminished or absent protective sensation, impaired proprioception, and motor dysfunction, resulting in foot deformities and abnormal pressure distribution. These changes increase the risk of unnoticed trauma and subsequent ulcer formation. Autonomic neuropathy causes decreased sweating, leading to dry, cracked skin that becomes a portal of entry for pathogens. Peripheral arterial disease further impairs blood flow, delaying wound healing and increasing susceptibility to infection. Additionally, hyperglycemia-induced immune dysfunction impairs neutrophil activity, reducing the body's ability to combat infections effectively(7).

Certain risk factors predispose individuals to diabetic foot disease, including male sex, age over 50, diabetes duration exceeding ten years, poor glycemic control with HbA1c above 7%, a history of previous foot ulcers or amputations, and the presence of microvascular complications such as nephropathy and retinopathy. Structural deformities like hammer toes, claw toes, and Charcot joints further contribute to ulcer risk. Clinical examination alone may fail to accurately assess the depth and extent of foot lesions, particularly when deep-seated infections or bone involvement are present. For this reason, the role of imaging in the early diagnosis, staging, and management of diabetic foot disease has become increasingly vital(8).

Radiological evaluation provides essential insights into the nature and severity of diabetic foot complications. Plain radiography remains a widely used initial imaging tool for detecting bony abnormalities, gas in soft tissues, foreign bodies, and joint deformities. However, its sensitivity is limited, especially in the early stages of osteomyelitis or in evaluating soft tissue involvement. Ultrasonography, particularly with Doppler capabilities, is a valuable modality for assessing superficial abscesses, fluid collections, and vascular integrity. It is particularly useful in evaluating peripheral arterial disease and mapping arterial perfusion in the lower limbs. Nevertheless, ultrasonography is operator-dependent and may not adequately visualize deep or complex anatomical structures(9).

Magnetic resonance imaging has emerged as the most reliable modality for diagnosing diabetic foot infections and related complications. Its high soft-tissue resolution allows for the early detection of osteomyelitis, bone marrow edema, abscesses, and sinus tracts. MRI is especially useful in differentiating cellulitis from abscesses and provides comprehensive anatomical detail that guides surgical and medical management (10). It also plays an important role in follow-up imaging to evaluate the effectiveness of therapy. Computed tomography, though less sensitive for soft tissue changes, is superior for delineating bony architecture, cortical destruction, and evaluating cases with complex fractures or suspected Charcot neuroarthropathy. It serves as an alternative when MRI is contraindicated due to the presence of metallic implants or patient intolerance(11).

In certain clinical scenarios, nuclear medicine techniques, including three-phase bone scintigraphy and labeled white blood cell scans, provide valuable information for distinguishing infection from sterile inflammation or Charcot arthropathy. While sensitive, these scans lack specificity and are often utilized in conjunction with other imaging modalities. The integration of various imaging tools allows for a holistic assessment, enabling timely interventions and reducing the risk of complications such as amputation or systemic sepsis(12).

Radiological imaging not only aids in the diagnosis but also serves a critical role in monitoring the progression of disease and response to therapy. With the growing prevalence of diabetes and its associated complications, the need for standardized imaging protocols and greater clinician awareness has become increasingly important. Early identification of diabetic foot complications, facilitated by radiological imaging, can significantly reduce healthcare costs, improve patient quality of life, and lower the incidence of limb-threatening outcomes. As diagnostic technologies advance and access improves, the incorporation of imaging into routine diabetic care will be essential to mitigating the burden of diabetic foot disease on individuals and healthcare systems alike(13).

The primary aim of this study is to diagnose diabetic foot disease at an early stage, particularly before the development of overt ulcers. It also seeks to evaluate the role of various radiological modalities in the early detection and monitoring of diabetic foot pathology. By identifying the disease in its initial phases, appropriate interventions can be implemented promptly to prevent progression to advanced stages and reduce the risk of complications.

MATERIALS AND METHODS

This prospective observational study was conducted in the Department of Radiodiagnosis at Maharani Laxmi Bai Medical College, Jhansi, involving diabetic patients with suspected early-stage foot complications. Patients were evaluated using a combination of radiological modalities including plain radiography, ultrasonography with Doppler, and magnetic resonance imaging (MRI). Inclusion criteria encompassed clinically diagnosed diabetics presenting with foot symptoms suggestive of neuropathy, ischemia, or infection. Imaging findings were recorded, correlated with clinical parameters, and monitored over time to assess disease progression. Exclusion criteria included patients with non-diabetic foot pathology or contraindications to MRI. Ethical clearance and informed consent were obtained prior to enrollment.

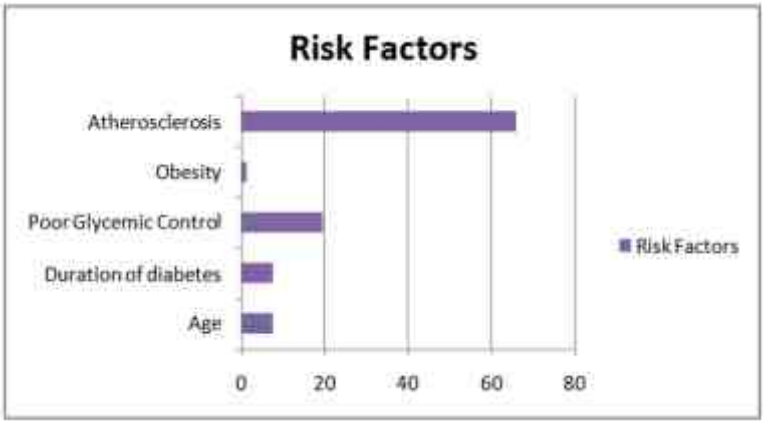
RESULTS

The study population (n=96) showed a predominance of middle-aged individuals, with the highest representation in the 46–60 years group (38.54%), followed by the 31–45 years group (30.20%). Younger (<30 years) and older (>70 years) participants were less represented. Gender-wise, males comprised the majority (58.33%) compared to females (41.66%). This distribution suggests a slightly older and male-skewed population, which may influence the study outcomes based on age and sex-related variables.

Table 1: Case distribution in study population (n=96)

Clinical features	Number of patients	Percentage
Symptomatic	64	66.67%
Asymptomatic	32	33.33%
Total	96	100.00%

In the study population of 96 patients, two-thirds (66. 67%) were symptomatic, while one-third (33.33%) were asympto-matic. This indicates a higher prevalence of clinically evident cases at presentation. The predominance of symptomatic individuals may reflect the tendency of patients to seek medical attention only upon symptom onset. This distribution is important for interpreting disease burden and evaluating diagnostic strategies.



Graph 1: Distribution of cases according to the Risk factors (n=96)

Atherosclerosis was the most common risk factor, present in 66% of cases, followed by poor glycemic control (19.61%). Age and diabetes duration contributed equally (~7%), while obesity was least prevalent (1.38%). This highlights the dominant role of vascular and metabolic dysfunction in the study population.

Table 2: Distribution of cases according to the Clinical presentation (n=96)

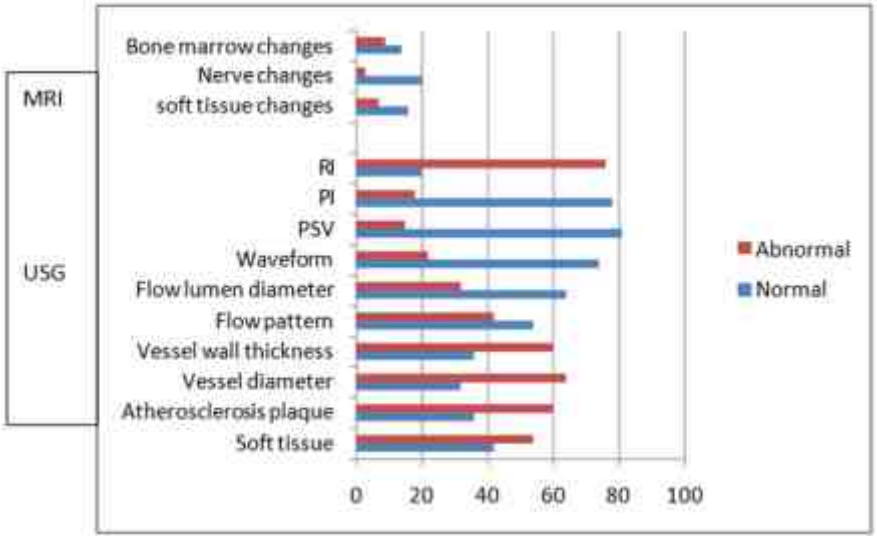
Clinical presentation	No	Percentage
Asymptomatic	32	33.33%
Neuropathic Pain	55	58.56%
Tingling sensation	19	20.72%
Numbness	10	2.76%
Weakness	15	16.57%
Other	14	14.92%

Neuropathic pain was the most common clinical presentation, reported in 58.56% of patients, followed by tingling (20.72%) and weakness (16.57%). One-third (33.33%) of cases were asymptomatic. Less frequent symptoms included numbness (2.76%) and other complaints (14.92%), reflecting varied neuropathic involvement.

Table 3: Distribution of Cases Based on Primary Modalities (n=96)

Modality	Number of patients	Percentage
Ultrasound	96	100.00%
MRI	23	24.00%
Total	96	100.00%

Ultrasound was the universal screening tool, used in 100% of the cases, highlighting its role as the primary imaging modality. MRI was utilized in 24% of patients, likely for further evaluation or confirmation. This indicates the reliance on ultrasound for initial assessment, with selective MRI use for detailed analysis.



Graph 2: Variables used in each modality

Ultrasound revealed high abnormality rates in vessel diameter (64), soft tissue (54), and atherosclerotic plaques (60), indicating prevalent vascular changes. Color and spectral Doppler abnormalities further supported impaired blood flow dynamics. MRI detected soft tissue, nerve, and bone marrow changes in fewer cases, reinforcing its supplementary diagnostic value.

Table 4: Distribution of cases according to diagnosis on Primary modality

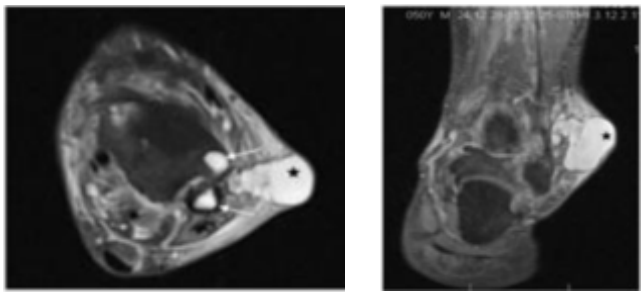
Modality	Normal	Abnormal	Total
Ultrasound	23	73	96
MRI	09	14	23

Ultrasound detected abnormalities in 73 out of 96 cases, demonstrating its high diagnostic yield. MRI revealed abnormalities in 14 of 23 cases, reinforcing its value in selected evaluations. Both modalities together provided complementary insights into disease detection.

Table 5: Diagnostic Capability of Primary Modalities

Modalities	Positive	Negative	Diagnostic Capability
USG (n=96)	73	23	76%
MRI (n=23)	14	09	60%

Ultrasound showed a higher diagnostic capability (76%) compared to MRI (60%), identifying more positive cases. This supports USG as the primary screening tool in the study. MRI, though less sensitive, served as a valuable adjunct in complex or equivocal cases.



A MRI IMAGES B

Figure 1: MRI scan of the above patient PD FAT SAT (A) Axial section & (B) Coronal section showing a hyperintense collection in the subcutaneous plane extending within adjacent fibula and tibia bone (arrow). There is extensive subcutaneous & intramuscular edema, all features are consistent with chronic osteomyelitic changes.

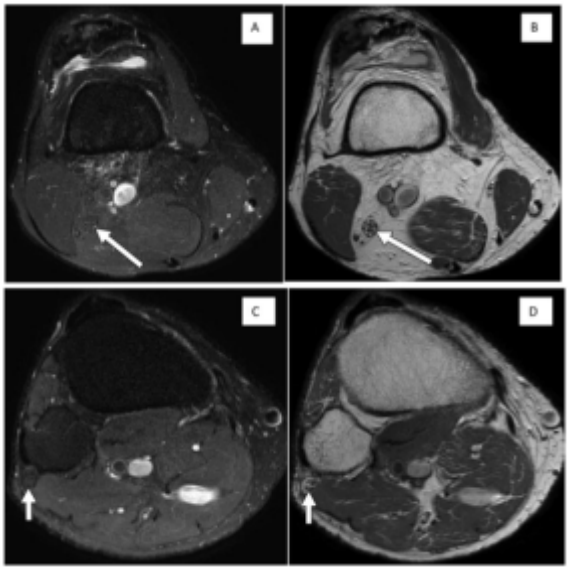


Figure 2: The image caption describes findings in a 66-year-old man with a history of uncontrolled diabetes mellitus who presented with knee pain but no neuropathic symptoms. Sequential axial MRI images including fat-suppressed proton density (labeled A and C) and non fat-suppressed proton density (labeled B and D) show enlarged tibial nerves (indicated by arrows in A and B) and common peroneal nerves (arrows in C and D). These nerves exhibit atrophic-appearing fascicles and prominent intraneurial fat, suggestive of chronic diabetic neuropathic changes despite the absence of overt symptoms.

ULTRASOUND IMAGES

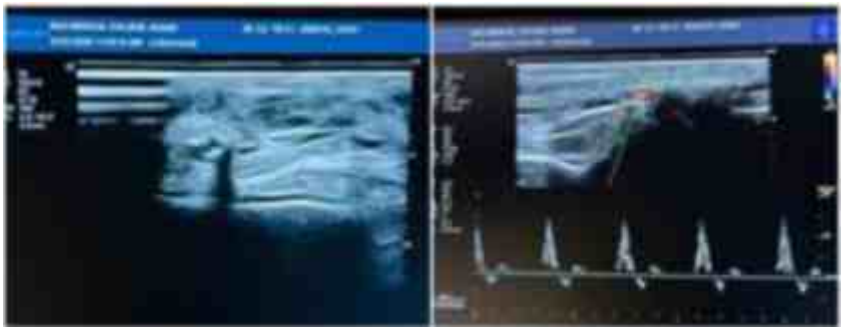


Figure 2: A 38-year-old male patient with uncontrolled diabetes, HbA1c of 8, (A) Wall thickening along anterior tibial artery (ATA) on gray scale, (B) Color Doppler showing aliasing but normal triphasic waveform on spectral Doppler.

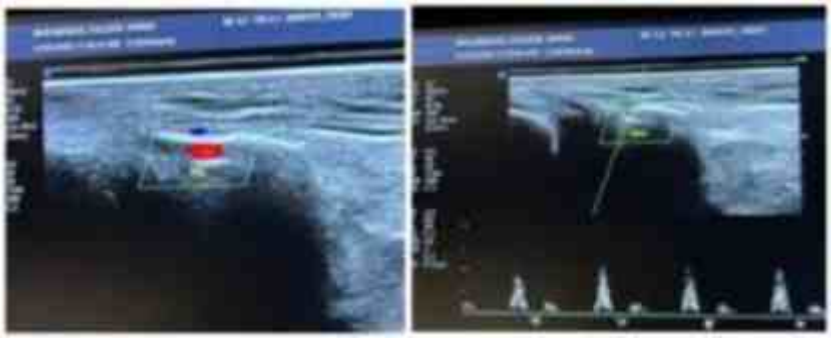


Figure 3: Same above patient (A) Wall thickening along Dorsalis Pedis artery (DPA) with laminar forward blood flow on Color Doppler scan, (B) showing normal triphasic waveform on spectral Doppler.

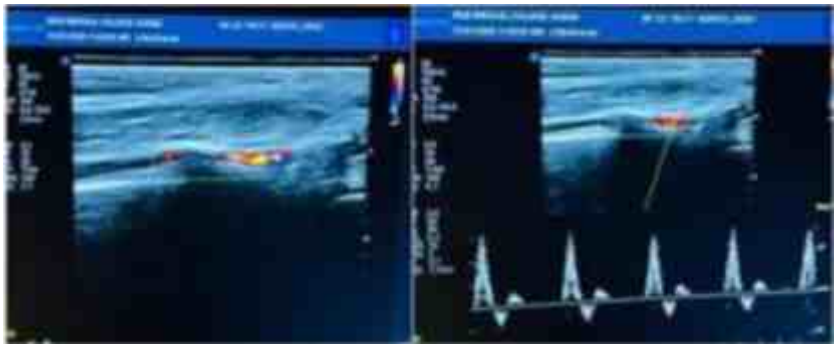


Figure 4: Same above patient (A) Wall thickening along Posterior Tibial Artery (PTA) with aliasing flow on Color Doppler, (B) showing normal triphasic waveform on spectral Doppler.

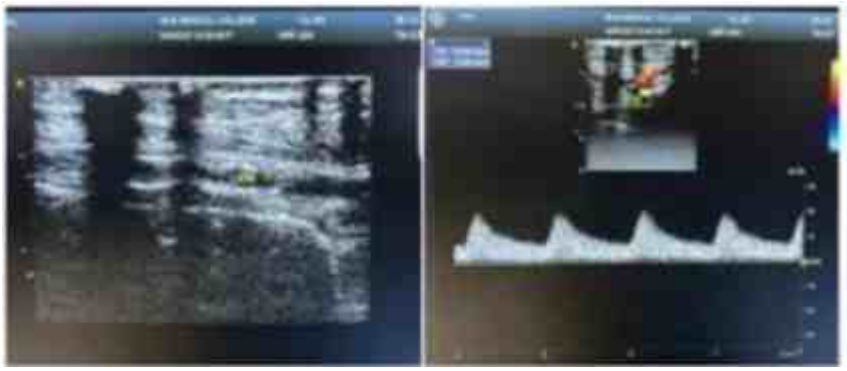


Figure 5: A 46-year-old patient with uncontrolled diabetes, HbA1c of 12, (A) Significant wall thickening along Anterior Tibial Artery (ATA), (B) with a continuous monophasic arterial flow in one direction (forward) throughout the cardiac cycle on duplex scan suggestive of proximal arterial obstruction.

DISCUSSION

Our findings reveal a predominance of middle-aged individuals, particularly those aged 46–60 years (38.54%), and a male majority (58.33%), aligning with Vanherwegen AS et al. (2023), who found that 72% of diabetic foot ulcer patients were male and more prone to severe infections, likely due to poorer vascular health and higher smoking rates. Similarly, Kuguyo O et al. (2023) reported a 53% prevalence of diabetic foot complications, with male sex, poor foot care, and neuropathy as key risk factors, reinforcing the impact of age and gender on disease outcomes(14, 15).

Our findings show that among 96 patients, 66.67% were symptomatic and 33.33% were asymptomatic, indicating a higher prevalence of clinically evident cases. This suggests patients often seek care only after symptom onset, impacting early detection and intervention. Similar results were reported by Abu-Jableh W et al. (2024) and Ikem RT et al. (2005), who also observed a predominance of symptomatic presentations, highlighting challenges in timely diagnosis and disease burden estimation(16, 17).

Our findings indicate that atherosclerosis was the most common risk factor (66%), followed by poor glycemic control (19.61%), while age and diabetes duration each contributed ~7%, and obesity was least prevalent (1.38%), highlighting the central role of vascular and metabolic dysfunction. This is consistent with Fang M et al. (2023), who identified vascular disease, poor glycemic control, and long diabetes duration as key contributors to DFD and its complications. Similarly, Fan Z et al. (2025) found age, diabetes duration, and glycemic control significantly associated with diabetic foot ulcers, reinforcing the importance of early vascular and metabolic risk management (18, 19).

Our findings show that ultrasound was used in 100% of cases as the primary screening tool, while MRI was employed in 24% for further evaluation. This reflects the standard practice of relying on ultrasound for initial assessment and using MRI selectively for detailed analysis. Similar approaches were reported by López-Moral M et al. (2024) and Ye H et al. (2025), confirming the diagnostic value of ultrasound and complementary role of MRI(20, 21)

Our findings revealed high ultrasound abnormality rates in vessel diameter (64 cases), soft tissue (54), and atherosclerotic plaques (60), with Doppler confirming impaired blood flow, indicating widespread vascular pathology. This aligns with Oduola-Owoo LT et al. (2022), who reported abnormal Doppler waveforms and significant plaque presence in posterior tibial and dorsalis pedis arteries in T2DM patients, supporting ultrasound's value in early vascular assessment. Additionally, Allam MF et al. (2023) emphasized MRI's role in differentiating infectious from non-infectious edema using chemical shift and Dixon sequences, reinforcing MRI's supplemental role in detailed diabetic foot evaluation(22, 23).

Our findings show that ultrasound detected abnormalities in 73 of 96 cases, highlighting its high diagnostic yield, while MRI revealed abnormalities in 14 of 23 cases, supporting its role in selected evaluations. The combined use of both modalities offered complementary diagnostic insights. Similar results were reported by López-Moral M et al. (2024) and Mahendra M et al. (2017), emphasizing the utility of ultrasound as a primary tool and MRI for detailed assessment(20, 24).

Our findings show that ultrasound had a higher diagnostic capability (76%) compared to MRI (60%), highlighting its value as a primary screening tool, while MRI served as a valuable adjunct in complex cases. This aligns with López-Moral M et al. (2024), who demonstrated that ultrasound had near-perfect sensitivity and specificity for detecting osteomyelitis in DFUs, supporting its use in early, non-invasive diagnosis. Similarly, Mahendra M et al. (2017) reported MRI's high sensitivity and specificity for tenosynovitis, reinforcing its role in assessing deep infections and aiding surgical planning in complicated diabetic foot cases(20, 24).

CONCLUSION

The study concludes that early diagnosis of diabetic foot disease is crucial for effective management and prevention of severe complications such as ulcers, infections, and amputations. Radiological modalities play a pivotal role in detecting subtle changes in soft tissue, vascular status, and bone involvement even before clinical signs become evident. MRI emerged as the most sensitive tool for early detection, while ultrasonography and Doppler studies provided valuable insights into vascular compromise. Integrating radiological evaluation into routine diabetic foot assessment enables timely intervention, improved patient outcomes, and reduced healthcare burden associated with advanced diabetic foot complications.

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