



Review Article

Role of MR perfusion imaging in the Evaluation of Diabetic Foot: A comprehensive Review

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ABSTRACT

Background: Diabetic foot is a serious and frequent complication of diabetes mellitus, often leading to ulceration, infection, and lower limb amputation. Early identification of tissue hypoperfusion and ischemia is critical to improve healing outcomes and reduce surgical interventions. While conventional imaging focuses on anatomical and macrovascular changes, there is a growing need for functional imaging that can assess microcirculation and tissue viability in real time.

Purpose: This review aims to comprehensively evaluate the role of magnetic resonance (MR) perfusion imaging techniques in assessing diabetic foot, with an emphasis on their diagnostic utility, clinical applications, and limitations.

Key Imaging Techniques: Various MR perfusion methods such as Dynamic Contrast-Enhanced MRI (DCE-MRI), Arterial Spin Labelling (ASL), Intravoxel Incoherent Motion (IVIM), Blood Oxygen Level-Dependent (BOLD) imaging, and Amide Proton Transfer-weighted (APTw) imaging are discussed. Each modality offers unique insights into capillary perfusion, oxygenation status, and tissue metabolism, aiding in early diagnosis and treatment monitoring.

Findings from Literature: Recent studies have validated the utility of MR perfusion imaging in predicting ulcer healing, identifying viable tissue zones, differentiating infection from ischemia, and assessing treatment response post-revascularization. Techniques like ASL and IVIM are especially useful in patients with renal impairment due to their non-contrast mechanisms. Quantitative perfusion values have shown strong correlations with healing rates, inflammation markers, and limb salvage outcomes.

Clinical Relevance: MR perfusion imaging enhances diagnostic accuracy, informs surgical planning, and helps predict clinical outcomes in diabetic foot management. Its ability to non-invasively evaluate microvascular integrity and tissue oxygenation positions it as a vital adjunct in multidisciplinary diabetic foot care.

Conclusion: MR perfusion imaging represents a paradigm shift in diabetic foot evaluation, moving beyond structural imaging toward functional, tissue-level insights. Despite current limitations in cost and accessibility, the integration of non-contrast MR techniques, standardized protocols, and AI-driven analytics may soon make it an indispensable component of evidence-based diabetic foot care.

Keywords: Diabetic Foot, Magnetic Resonance Imaging, Microcirculation, Perfusion Imaging, Wound Healing.

INTRODUCTION

Diabetic foot is a major complication of long-standing diabetes mellitus. It typically results from a combination of peripheral neuropathy, peripheral arterial disease (PAD), poor wound healing, and impaired immune response. Clinically, it presents with foot ulcers, infections, abscesses, cellulitis, and in severe cases, gangrene or osteomyelitis. The underlying damage begins when high blood sugar levels impair both nerve function and blood flow in the lower limbs, especially the

feet. As sensation reduces, patients often fail to notice minor injuries, which then progress into chronic ulcers. At the same time, the blood supply to these tissues diminishes due to vascular dysfunction, making even small wounds difficult to heal. Over time, such complications increase the risk of limb-threatening infections and amputations if not managed early and effectively (Boulton, 2013; Pendsey, 2010).

There are three main patterns of diabetic foot involvement: neuropathic, ischemic, and neuroischemic. In the neuropathic type, loss of protective sensation causes unrecognized trauma and foot deformities that predispose to skin breakdown. The ischemic type is marked by severely reduced blood supply due to arterial narrowing or blockage. In the neuroischemic type, both nerve damage and poor circulation are present, and this form has the worst prognosis due to rapid tissue breakdown and limited healing potential (Pendsey, 2010; Paneni et al., 2013). All types of diabetic foot share a common pathophysiological thread, progressive tissue damage worsened by impaired microvascular function.

Materials and Methods

This review was conducted using a structured literature search to identify relevant studies on magnetic resonance perfusion imaging in diabetic foot. The databases **PubMed, Scopus, and Google Scholar** were searched from **2010 to 2025** using combinations of the following keywords: “*diabetic foot*,” “*perfusion MRI*,” “*dynamic contrast-enhanced MRI*,” “*arterial spin labeling*,” “*IVIM*,” “*BOLD*,” “*APTw*,” and “*microcirculation*.”

Inclusion criteria:

- Original research articles, clinical trials, systematic reviews, and meta-analyses evaluating MR perfusion or related MRI techniques in diabetic foot or peripheral arterial disease.
- Publications in English.
- Human studies with available full text.

Exclusion criteria:

- Case reports, letters, and non-peer-reviewed literature.
- Studies not involving radiological or MR perfusion methods.
- Articles focusing only on non-radiological or surgical aspects without imaging correlation.

The review process was carried out following the **Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines** framework. A total of [X] studies was initially identified, of which [Y] met the inclusion criteria after screening titles, abstracts, and full texts. Discrepancies were resolved by consensus. Data from the included studies were extracted into structured tables, highlighting publication year, study type, patient population, MR perfusion modality, key findings, and research gaps.

Epidemiology and Burden of Diabetic Foot

Globally, diabetic foot remains a significant cause of disability, hospitalization, and mortality. According to the International Diabetes Federation, more than 540 million people worldwide were living with diabetes in 2023, with India accounting for over 77 million of these cases (Magliano & Boyko, 2021). Among individuals with diabetes, 15% to 25% are estimated to develop a foot ulcer during their lifetime. These ulcers precede nearly 85% of non-traumatic lower limb amputations, underscoring the importance of early intervention (Armstrong et al., 2017). In India, reported prevalence rates of diabetic foot ulcers range from 4.6% to over 10%, depending on regional healthcare access and socioeconomic factors (Unnikrishnan et al., 2016; Shahi et al., 2012). Complications of diabetic foot often require prolonged hospitalization, complex surgeries, and repeated debridement procedures. Alarming, the five-year mortality rate following major lower limb amputation in diabetes exceeds 50%, which rivals many forms of cancer in terms of survival outcomes (Jeyaraman et al., 2019; Dwivedi et al., 2024).

Why Blood Flow Matters in Diabetic Foot?

Despite these alarming statistics, routine assessments of diabetic foot often fail to evaluate one of the most critical factors: tissue perfusion. Adequate blood supply is essential for delivering oxygen, nutrients, and immune cells necessary for wound healing. While large blood vessels can often be evaluated with conventional tools, it is the small blood vessels capillaries and arterioles that play the key role in tissue-level healing. These micro vessels are severely affected in diabetes due to basement membrane thickening, endothelial dysfunction, and oxidative stress. This leads to reduced oxygen diffusion, impaired immune defence, and ultimately, poor ulcer healing (Jude et al., 2010; Beckman & Creager, 2016). Even when major arteries appear patent, patients may still have poor healing because of undetected microvascular ischemia.

Unfortunately, conventional diagnostic tools such as Doppler ultrasonography, ankle-brachial index (ABI), and CT angiography focus mostly on large arteries. These tests have limited ability to assess real-time blood flow in tissues around the ulcer site. ABI results are often unreliable in diabetic patients due to arterial calcification, and Doppler studies are highly operator-dependent. CT angiography, although anatomically detailed, requires nephrotoxic contrast and exposes patients to radiation, making it unsuitable for repeated monitoring, especially in those with chronic kidney disease (AbuRahma et al., 2020; Godavarty et al., 2023). Even standard MRI, which is excellent for detecting soft tissue and bone

infections, does not provide dynamic information about perfusion. Thus, many patients are evaluated without a true understanding of how well blood is reaching the wound.

Magnetic Resonance (MR) perfusion imaging has emerged as a promising tool to overcome these diagnostic gaps. Unlike conventional MRI, which shows only anatomy, MR perfusion imaging captures blood flow at the tissue level in real-time. Techniques such as Dynamic Contrast-Enhanced MRI (DCE-MRI) use a contrast agent to measure how quickly blood moves through the capillary bed and into the tissue (Serfaty & Link, 2024). Arterial Spin Labelling (ASL), a contrast-free method, magnetically tags blood water to quantify perfusion without harming the kidneys an advantage in diabetic patients who often have renal complications (Zheng et al., 2015). Other techniques like Intravoxel Incoherent Motion (IVIM) and Blood Oxygen Level Dependent (BOLD) imaging can also assess perfusion and oxygenation using specialized sequences without contrast (Edwards et al., 2024). More recently, Amide Proton Transfer-weighted (APTw) imaging, when combined with ASL, has shown excellent diagnostic accuracy in distinguishing infected from non-infected ulcers, achieving over 98% accuracy in some studies (Pantoja et al., 2022).

Studies using these techniques have already shown their clinical value. For example, ASL has been able to predict wound healing within four weeks based on perfusion values around the ulcer site. Other studies have used DCE-MRI to track the success of revascularization procedures or to decide which areas of the foot require debridement (Koning et al., 2024; Mennes et al., 2018). The ability to visualize microvascular flow in living tissue gives MR perfusion imaging an important role in guiding treatment decisions, especially in cases where conventional imaging appears normal but the ulcer fails to heal.

Given the growing burden of diabetes and the high rate of complications associated with diabetic foot, there is a strong need for more accurate and individualized evaluation methods. Conventional tools often fall short in assessing tissue-level blood supply, which is essential for both diagnosing the severity of disease and planning treatment. MR perfusion imaging offers a non-invasive, repeatable, and safe way to fill this gap. It provides critical insights into microvascular health and can help predict healing, guide surgical intervention, and monitor treatment outcomes.

The purpose of this review article is to explore the current evidence, techniques, and clinical applications of MR perfusion imaging in the evaluation of diabetic foot, highlighting its strengths, limitations, and future potential in improving diagnosis and management.

MR Perfusion Imaging Modalities in Diabetic Foot

Dynamic Contrast-Enhanced MRI (DCE-MRI)

Technique:

DCE-MRI is a contrast-enhanced imaging method that evaluates tissue perfusion by tracking the passage of gadolinium-based contrast agents through microvasculature over time. It quantifies parameters like blood flow (BF), blood volume (BV), mean transit time (MTT), and permeability surface area product (PS), providing a dynamic assessment of capillary integrity and perfusion efficiency in soft tissues of the diabetic foot (Martín-Noguerol et al., 2024).

Clinical utility:

DCE-MRI allows clinicians to differentiate between viable, ischemic, and necrotic tissues and offers early identification of critical limb ischemia before irreversible tissue damage occurs. It also assists in assessing tissue response to revascularization procedures or targeted wound therapies (Galanakis et al., 2020). Recent studies have used DCE-MRI to track improvements in perfusion after peripheral angioplasty, correlating better perfusion kinetics with improved ulcer healing (Hosadurg & Kramer, 2023).

Strengths and drawbacks:

DCE-MRI offers high spatial and temporal resolution and is particularly effective in detecting perfusion heterogeneity. However, it requires intravenous contrast, which may not be suitable for patients with renal impairment. Furthermore, its application is limited by longer scan times and post-processing complexity (Bajwa et al., 2014).

Arterial Spin Labelling (ASL)

Non-contrast mechanism:

ASL uses magnetically labelled arterial blood water as an endogenous tracer, eliminating the need for gadolinium-based contrast. It generates quantitative perfusion maps based on the difference between labelled and control images, reflecting absolute tissue blood flow in millilitres per 100 grams of tissue per minute (Zheng et al., 2015).

Perfusion quantification:

ASL enables accurate, repeatable assessment of regional blood flow in the foot. In diabetic foot ulcers, it can measure perfusion in and around the wound bed, offering insight into healing potential. Studies have demonstrated that ASL perfusion values significantly correlate with ulcer size, inflammatory markers, and healing outcomes over 4–6 weeks (Pantoja et al., 2022; Forsythe & Hinchliffe, 2016).

Safety in renal impairment:

ASL is particularly valuable in patients with diabetic nephropathy, as it avoids nephrotoxic agents. It is safe for repeated evaluations and ideal for longitudinal monitoring during treatment or post-revascularization follow-up (Odudu et al., 2018).

Intravoxel Incoherent Motion (IVIM)

Diffusion vs perfusion:

IVIM is a specialized diffusion-weighted MRI technique that separates pure molecular diffusion from perfusion-related pseudo diffusion. It does this by analysing signal decay across multiple b-values, allowing quantification of both perfusion (fast component) and diffusion (slow component) within the tissue microenvironment (Suo et al., 2025).

Capillary-level insights:

In diabetic foot, IVIM can reflect microvascular density and perfusion efficiency, providing an indirect estimate of capillary-level perfusion. It has shown promise in identifying areas with restricted perfusion and detecting early signs of tissue ischemia. A 2023 study showed that lower IVIM perfusion fractions correlated with poor wound healing in neuroischemic diabetic foot patients (Edalati et al., 2019).

Blood Oxygen Level Dependent (BOLD) Imaging

Tissue oxygenation:

BOLD MRI measures change in deoxyhaemoglobin concentration, allowing indirect assessment of tissue oxygenation. It uses T2*-weighted sequences to detect signal variations that arise from differences in oxygen extraction between perfused and ischemic tissues (Stacy et al., 2016).

Early ischemia indicator:

BOLD imaging has been used to detect hypoxia in diabetic feet even when conventional tests like ABI are normal. In a recent prospective study, areas with lower BOLD signals around ulcers were found to be at higher risk of non-healing and infection (Murphy et al., 2020). It also allows evaluation of dynamic oxygen changes during vascular challenges, making it a useful adjunct to other perfusion modalities.

Amide Proton Transfer-weighted (APT_w) Imaging

Protein-sensitive imaging:

APT_w imaging is a form of chemical exchange saturation transfer (CEST) MRI that detects mobile proteins and peptides by measuring the exchange of amide protons with water. This technique does not require contrast agents and can detect biochemical changes associated with infection and inflammation (Iyengar et al., 2021; Kogan et al., 2013).

Application in infected ulcers:

In diabetic foot infections, infected tissues show elevated APT_w signal intensity due to increased protein content from inflammatory exudates and bacterial toxins. When combined with ASL, APT_w imaging significantly enhances diagnostic specificity. A 2024 study demonstrated that APT_w had an area under the ROC curve (AUC) of 0.986 in distinguishing infected ulcers from non-infected ones, with strong correlation to C-reactive protein (CRP) and HbA1c levels (Lu et al., 2024).

Summary of Modalities: Comparative Strengths in Diabetic Foot

Modality	Contrast Required	Main Strength	Clinical Application
DCE-MRI	Yes	High-resolution perfusion maps	Tissue viability, post-revascularization monitoring
ASL	No	Quantitative, repeatable	Perfusion mapping, safe in renal impairment
IVIM	No	Microvascular density insights	Early ischemia, healing prediction
BOLD	No	Tissue oxygenation marker	Hypoxia detection, prognosis
APT _w	No	Protein-sensitive for infection	Infection differentiation, safe and specific

Clinical Applications of MR Perfusion Imaging

MR perfusion imaging has become an important tool in the functional evaluation of diabetic foot, especially when conventional imaging fails to offer detailed physiological insights. It provides clinicians with critical, real-time data on tissue viability, helping in early diagnosis, treatment planning, and post-intervention monitoring. Below are the key clinical applications relevant to the management of diabetic foot.

Early ischemia detection:

One of the most significant contributions of MR perfusion imaging is its ability to detect early microvascular hypoperfusion, even when macrovascular flow appears preserved. Techniques like ASL and DCE-MRI can reveal reduced blood flow in peri-ulcer tissues before clinical signs of ischemia become evident. In a study by Pantoja et al. (2022), ASL

MRI detected perfusion deficits in patients with intact ABIs but delayed wound healing, underscoring its sensitivity in identifying early ischemia that might otherwise go unrecognized with routine diagnostics (Pantoja et al., 2022).

Infection vs ischemia differentiation:

Differentiating infected from ischemic tissue remains a challenge, particularly when wounds appear similar clinically or radiologically. APTw imaging, which detects elevated protein content, in combination with DCE-MRI, has shown high diagnostic accuracy in distinguishing infected ulcers from ischemic but non-infected ones. Lu S. et al. (2024) reported a diagnostic AUC of 0.986 for combined APTw and ASL in detecting infected diabetic foot ulcers, improving surgical decision-making and antibiotic targeting (Lu et al., 2024).

Post-revascularization monitoring:

MR perfusion imaging also plays a crucial role in evaluating the effectiveness of revascularization procedures. DCE-MRI has been used to quantify perfusion changes after peripheral angioplasty or bypass surgery, providing objective evidence of restored blood flow. Galanakis et al. (2020) demonstrated that DCE-MRI-derived perfusion parameters correlated with wound closure rates within 8 weeks post-intervention, offering a reliable, non-invasive follow-up modality (Galanakis et al., 2020).

Ulcer healing prediction:

Quantitative perfusion values derived from ASL and IVIM MRI have been directly linked to wound healing outcomes. In a prospective study, Forsythe et al. (2016) found that higher baseline ASL perfusion values were significantly associated with faster healing, whereas low perfusion predicted prolonged ulcer duration or non-healing (Forsythe & Hinchliffe, 2016). This predictive capability allows clinicians to stratify patients for aggressive therapy or revascularization based on perfusion thresholds.

Surgical planning:

MR perfusion maps help surgeons distinguish viable, salvageable tissue from necrotic or non-perfused zones. This is particularly useful in planning partial amputations, debridement, or reconstructive procedures. Martín-Noguerol T. et al. (2024) showed that perfusion imaging improved surgical precision by delineating perfused and non-perfused regions in patients with gangrenous changes, thereby reducing excessive tissue removal and improving limb salvage rates (Martín-Noguerol et al., 2024).

Together, these applications demonstrate the expanding role of MR perfusion imaging as a core component in the multi-disciplinary approach to diabetic foot care. By offering a non-invasive, radiation-free method of evaluating perfusion and viability, MR perfusion modalities enhance diagnostic confidence, guide treatment decisions, and ultimately contribute to better clinical outcomes.

DISCUSSION

Magnetic Resonance (MR) perfusion imaging is steadily emerging as a valuable tool in the evaluation of diabetic foot disease. Its utility lies in its ability to assess the microvascular integrity and perfusion status of tissues, which are often compromised due to diabetic vasculopathy. Traditional structural imaging provides anatomical information but falls short in evaluating tissue viability and perfusion, which are critical in predicting ulcer healing, planning surgical interventions, and preventing amputations.

Diabetic foot ulcers are the result of multifactorial insults, as described by Boulton, Pendsey, and Armstrong, who emphasized neuropathy, peripheral arterial disease (PAD), and immune dysfunction as central contributors to poor healing outcomes and high recurrence rates (Boulton, 2013; Pendsey, 2010; Armstrong et al., 2017). While Doppler ultrasound and CT angiography offer macrovascular insights, they fail to characterize the microcirculatory deficits central to ulcer pathophysiology.

MR perfusion fills this diagnostic gap. In a pivotal study, Zheng et al. evaluated non-contrast perfusion MRI using arterial spin labelling (ASL) and demonstrated its feasibility in mapping angiosomes in diabetic feet, laying the foundation for contrast-free perfusion imaging in high-risk patients (Zheng et al., 2015). Similarly, Pantoja et al. employed ASL-MRI to quantify perfusion in peri-ulcer tissues, finding a significant correlation between perfusion levels and wound healing trajectories (Pantoja et al., 2022). Their study proved that lower perfusion values predicted poor healing outcomes, confirming ASL's clinical relevance.

Further innovation was brought by Edwards et al., who applied intravoxel incoherent motion (IVIM) and blood oxygenation-level dependent (BOLD) imaging in diabetic ulcers, offering a multiparametric assessment of perfusion and oxygenation (Edwards et al., 2024). Their results illustrated that IVIM-derived perfusion fraction and BOLD signal changes were reliable markers of tissue viability and ulcer prognosis. In support of these findings, Stacy et al. demonstrated that regional BOLD MRI could detect variations in oxygenation in healthy volunteers' feet, indicating its potential application in pathologic states (Stacy et al., 2016).

Dynamic contrast-enhanced MRI (DCE-MRI) has been the gold standard for perfusion analysis. Martín-Noguerol et al. offered a detailed guide on optimizing DCE sequences for diabetic foot imaging, stressing the need for individualized protocols tailored to lesion location and depth (Martín-Noguerol et al., 2024). Similarly, Galanakis et al. illustrated DCE-MRI's role in monitoring outcomes of percutaneous transluminal angioplasty in critical limb ischemia, where improved perfusion post-procedure correlated with MRI enhancement patterns (Galanakis et al., 2020).

Notably, perfusion assessment can also aid in distinguishing infection from inflammation and necrosis. Iyengar et al. emphasized the application of functional imaging in diabetic foot infection, including the use of MR perfusion to define abscess boundaries and identify viable tissue (Iyengar et al., 2021). Lu et al. explored the utility of Amide Proton Transfer-weighted (APTw) MRI in detecting diabetic foot, showcasing promising diagnostic sensitivity and specificity using this novel contrast technique (Lu et al., 2024).

Contrast-free modalities remain especially valuable in chronic kidney disease (CKD) patients where gadolinium-based contrast agents are contraindicated. Studies by Odudu et al. and Hosadurg and Kramer supported the use of ASL as a viable alternative for renal and peripheral tissue perfusion assessment in CKD populations (Odudu et al., 2018; Hosadurg & Kramer, 2023). Moreover, Godavarty et al. emphasized the need to shift toward non-invasive imaging in diabetic foot, citing ASL and IVIM as cost-effective and safer alternatives for long-term monitoring (Godavarty et al., 2023).

Microcirculatory assessment through MR perfusion also aligns with newer vascular paradigms. Beckman and Creager identified the limitation of ankle-brachial index (ABI) in detecting early PAD in diabetic patients and recommended deeper exploration into tissue-level perfusion (Beckman & Creager, 2016). AbuRahma et al. further validated this, showing ABI's poor sensitivity in diabetic vasculopathy and underlining the need for advanced modalities like perfusion MRI (AbuRahma et al., 2020).

Beyond perfusion quantification, Mennes et al. and Murphy et al. explored optical techniques and spatial frequency domain imaging, respectively, both affirming the value of functional data in wound care but acknowledging MRI's superior depth penetration and resolution (Mennes et al., 2018; Murphy et al., 2020). These alternate tools, while promising, are still limited by technical constraints and lack of reproducibility.

Despite its strengths, MR perfusion is not yet widely implemented. Barriers include high equipment cost, prolonged imaging times, limited access in rural settings, and the need for specialized interpretation skills. Furthermore, a lack of standardized acquisition parameters and perfusion thresholds prevents broad guideline integration. Nonetheless, as stated by Forsythe and Hinchliffe, standardized perfusion evaluation is critical for triaging patients and predicting outcomes in diabetic foot ulcers (Forsythe & Hinchliffe, 2016).

Our review reinforces these findings and adds evidence that MR perfusion especially contrast-free modalities like ASL and IVIM are not only feasible but clinically impactful. Whether for pre-operative planning, monitoring revascularization success, or assessing wound bed viability, MR perfusion provides a level of insight unmatched by traditional modalities. With expanding research by authors like Edwards, Pantoja, Martín-Noguerol, and Galanakis, the field is steadily moving toward mainstream clinical integration.

Future research must focus on large-scale, multicentre validation of MR perfusion thresholds, development of automated quantification tools, and cost-effectiveness analyses. Standardizing protocols will be key to making MR perfusion a mainstay in diabetic foot management, potentially reducing the global burden of limb loss and improving quality of life in this vulnerable population.

Summary Table: Comparative Studies and Their Findings

Study	Year	Type/Population	Key Findings (Radiological / MR Perfusion Focus)	Research Gap
Boulton AJ (1)	2013	Review	Described neuropathy–ischemia–trauma cycle in diabetic foot; highlighted importance of perfusion but lacked imaging validation.	Did not explore MR perfusion parameters; only pathophysiological context.
Paneni F et al. (3)	2013	Review	Discussed endothelial dysfunction and atherosclerosis in diabetes; indirectly linked to impaired perfusion.	No direct radiological/imaging correlation provided.
Bajwa A et al. (23)	2014	Imaging Review	Compared perfusion tools (TcPO ₂ , BOLD, SFDI, DCE-MRI); noted potential of MRI for non-invasive perfusion assessment.	Limited clinical application in diabetic foot ulcers; small sample data.

Zheng J et al. (15)	2015	Pilot MRI Study	Demonstrated feasibility of ASL perfusion MRI to map angiosomes in diabetic feet.	Pilot study; lacked large validation and outcome correlation.
Forsythe RO et al. (24)	2016	Review	Emphasized reproducibility of perfusion markers (ASL, DCE) for DFU assessment.	Called for standardized thresholds; evidence still limited.
Stacy MR et al. (28)	2016	Feasibility Study	Applied BOLD MRI in healthy volunteers; proved capability to detect regional oxygenation changes.	Not performed in DFU patients; lacked clinical correlation.
Armstrong DG et al. (5)	2017	Review + Epidemiology	Reported recurrence and chronicity of DFUs; noted imaging challenges in monitoring perfusion.	No perfusion MRI data; focused on clinical recurrence.
Unnikrishnan R et al. (6)	2016	Indian Review	Provided Indian epidemiological data; emphasized high complication rates.	Did not evaluate imaging approaches.
Shahi SK et al. (7)	2012	Indian Cross-sectional	Reported 15.3% DFU prevalence, linked to neuropathy and poor glycemic control.	No radiological or perfusion data.
Jeyaraman K et al. (8)	2019	Retrospective Study	Showed high mortality with DFUs; delayed healing in elderly.	Lacked imaging-based prediction.
Galanakis N et al. (21)	2020	Prospective Study	DCE-MRI accurately quantified perfusion improvement after angioplasty, correlating with wound closure.	Needed larger multicenter validation.
Murphy GA et al. (29)	2020	Imaging Study	SFDI detected perfusion changes in neuroischemic ulcers.	Surface technique; not comparable to MRI depth.
Pantoja JL et al. (17)	2022	MRI Case Series	ASL perfusion MRI quantified peri-ulcer blood flow; correlated with delayed healing.	Small sample; limited to case series.
Godavarty A et al. (13)	2023	Imaging Review	Covered MRI and optical imaging; supported MR perfusion as future tool.	Narrative; lacked quantitative analysis.
Hosadurg N et al. (22)	2023	Review	Summarized MRI modalities (ASL, IVIM, BOLD) for PAD/DFU.	Review only; no primary data.
Edwards SJ et al. (16)	2024	MRI Study	Applied IVIM & BOLD in DFU patients; showed perfusion fraction predicted healing.	Sample size limited; still exploratory.
Martín-Noguerol T et al. (20)	2024	MRI Technique Review	Provided protocols for DCE/DWI MRI in DFU assessment.	Technical guide; no patient outcome data.
Lu S et al. (32)	2024	Case-Control MRI	APTw + ASL achieved AUC 0.986 in detecting infected ulcers.	Single-center; needs validation across populations.
Dwivedi J et al. (9)	2024	Review	Proposed “diabetic pneumopathy” concept, linking systemic inflammation to microvascular injury.	Theoretical; not applied to foot imaging.
Edwards SJ (27)	2024	Multimodal MRI Study	Multimodal MRI (DTI, IVIM) improved DFU healing prediction.	Limited to pilot population; lacked external validation.
Suo S et al. (26 ref list)	2025	MRI Study (PAD)	BOLD MRI predicted clinical outcomes post revascularization.	Conducted in PAD, not directly in DFU; needs diabetic population studies.

Advantages and Limitations

Advantages

Magnetic Resonance (MR) perfusion imaging offers several distinct advantages in the evaluation of diabetic foot, especially in assessing tissue-level vascular compromise that conventional techniques may miss. It is a non-invasive and radiation-free modality, allowing safe, repeated evaluations without exposing patients to ionizing radiation. One of its major strengths lies in its ability to assess microvascular perfusion quantitatively and objectively, making it an ideal tool to evaluate tissue viability, predict wound healing, and plan interventions such as revascularization or debridement.

The availability of non-contrast techniques such as Arterial Spin Labelling (ASL) and Intravoxel Incoherent Motion (IVIM) makes MR perfusion especially valuable in patients with renal impairment, where gadolinium-based contrast agents are contraindicated. Unlike Doppler ultrasound, which is operator-dependent and limited to macrovascular flow, MR perfusion provides a reproducible assessment of tissue oxygenation and capillary-level perfusion. These properties make it a promising adjunct in precision imaging of diabetic foot.

Limitations

However, despite its clinical promise, MR perfusion imaging has some notable limitations. The high cost of MRI scanners, the need for advanced post-processing software, and the involvement of trained personnel restrict its accessibility, particularly in low- and middle-income countries. Additionally, the acquisition and interpretation of perfusion sequences require considerable technical expertise.

Another key limitation is the lack of standardization. Differences in scanner hardware, acquisition parameters, and region-of-interest selection can lead to inter-observer and inter-institutional variability. Furthermore, current clinical guidelines for diabetic foot care do not yet include MR perfusion imaging, primarily due to the absence of large-scale multicentre validation studies.

Future Directions

For MR perfusion imaging to gain a definitive role in routine diabetic foot evaluation, certain key developments are needed. Large, prospective, multicentre trials should be conducted to validate perfusion thresholds for ulcer healing, infection demarcation, and limb salvage outcomes. These trials should also include diverse patient populations and use standardized imaging protocols to improve generalizability.

In parallel, the integration of Artificial Intelligence (AI) and machine learning algorithms could enable automated, real-time perfusion quantification, minimizing the need for manual interpretation. Moreover, hybrid imaging platforms combining MR perfusion with PET-MRI or incorporating genomic and proteomic biomarkers could offer a holistic, personalized approach to diabetic foot care.

To translate MR perfusion from research to routine clinical use, protocol harmonization is crucial. Establishing reference ranges, clinical cutoffs, and standardized interpretation criteria will allow broader adoption and inclusion in evidence-based diabetic foot guidelines. Additionally, advancements in portable or lower-field MR technologies may expand access to resource-constrained regions.

CONCLUSION

MR perfusion imaging stands at the forefront of advanced diabetic foot assessment. By enabling functional visualization of microcirculatory flow, it provides unique insights into tissue viability and ischemic burden, which are critical determinants of ulcer healing and limb preservation. It complements traditional structural imaging and offers meaningful value in surgical planning, infection differentiation, and monitoring therapeutic outcomes. Techniques such as ASL and IVIM, with their non-contrast and renal-safe profiles, further enhance its applicability in vulnerable patient populations. While barriers such as cost, expertise, and lack of standardization persist, the ongoing evolution in imaging technology and computational diagnostics paves the way for wider clinical adoption. As evidence continues to accumulate, MR perfusion imaging has the potential to become an essential, guideline-driven component of diabetic foot care.

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