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Advanced Cardiac MRI Techniques Beyond Late Gadolinium Enhancement in Ischemic Heart Disease: Current Evidence and Future Directions

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ABSTRACT

***Background*:** Late gadolinium enhancement (LGE) cardiovascular magnetic resonance (CMR) has long been regarded as the reference standard for noninvasive detection and quantification of myocardial infarction in ischemic heart disease. While LGE provides robust visualization of focal replacement fibrosis, it has important limitations, including reduced sensitivity for diffuse interstitial fibrosis, dependence on gadolinium-based contrast agents, and limited ability to characterize dynamic or subtle myocardial injury. Advances in CMR technology over the past decade have expanded the role of cardiac MRI beyond qualitative scar imaging toward comprehensive, quantitative myocardial tissue characterization.

Aim: This review aims to summarize and critically appraise advanced cardiac MRI techniques beyond conventional LGE for the evaluation of ischemic heart disease, with emphasis on parametric mapping, myocardial strain imaging, quantitative perfusion, and artificial intelligence–based post-processing, highlighting their current evidence base, clinical applicability, and future potential from a radiodiagnostic perspective.

The review discusses native T1 and T2 mapping and extracellular volume quantification as tools for detecting diffuse myocardial fibrosis, edema, and subtle ischemic injury not readily apparent on LGE imaging. The role of CMR feature-tracking–derived myocardial strain in functional assessment and prognostication is examined, particularly in patients with ischemic cardiomyopathy. Advances in stress perfusion CMR, including quantitative myocardial blood flow and flow reserve mapping, are reviewed in the context of epicardial and microvascular ischemia. Technical innovations such as dark-blood and high-resolution LGE are addressed as refinements rather than replacements for conventional techniques. Emerging applications of artificial intelligence and deep learning for automated segmentation, scar quantification, and contrast-free viability assessment are also explored. Practical challenges, limitations, and barriers to widespread clinical implementation are highlighted.

Conclusion: Advanced cardiac MRI techniques are redefining the evaluation of ischemic heart disease by enabling quantitative, multiparametric assessment of myocardial structure, function, and perfusion beyond focal scar detection. As these techniques mature and become standardized, they are poised to complement and, in selected scenarios, extend beyond traditional LGE imaging, positioning cardiac MRI as a comprehensive precision imaging modality for ischemic heart disease.

Keywords: Cardiac MRI Techniques, Late Gadolinium Enhancement , Ischemic Heart Disease

INTRODUCTION

Ischemic heart disease remains a leading cause of left ventricular systolic dysfunction and heart failure worldwide. Accurate imaging assessment of myocardial injury, ischemia, and remodeling is essential for diagnosis, prognostication, and therapeutic decision-making. Among noninvasive imaging modalities, contrast-enhanced cardiac magnetic resonance imaging (CE-CMR) has emerged as a cornerstone technique because it uniquely integrates high-resolution anatomical imaging, functional assessment, perfusion evaluation, and tissue characterization within a single comprehensive examination [1].

Late gadolinium enhancement (LGE) imaging is the most widely used CE-CMR technique for the detection and quantification of myocardial infarction and myocardial fibrosis. By exploiting differences in gadolinium distribution between normal myocardium and areas of cell membrane disruption or extracellular matrix expansion, LGE provides direct visualization of irreversible myocardial injury with excellent spatial resolution and strong histopathologic correlation [2]. In patients with ischemic cardiomyopathy, the presence and transmural extent of LGE have been shown to predict regional functional recovery and clinical outcomes following coronary revascularization, establishing CE-CMR as a reference standard for myocardial viability assessment [3].

Despite its established clinical value, conventional LGE-based CE-CMR has important limitations. LGE relies on relative signal intensity differences between diseased and remote myocardium and therefore has reduced sensitivity for diffuse interstitial fibrosis, balanced ischemia, and early ischemic injury without focal scar formation. As a result, subtle or global myocardial abnormalities may be underestimated or missed using standard LGE techniques [4]. In addition, LGE predominantly provides qualitative or semi-quantitative information and does not fully characterize dynamic pathophysiologic processes such as myocardial edema or microvascular dysfunction, which are increasingly recognized as relevant in ischemic heart disease [5].

Dependence on gadolinium-based contrast agents represents another limitation of conventional CE-CMR. Although generally safe, gadolinium administration may be contraindicated or undesirable in patients with advanced renal dysfunction or in clinical scenarios requiring repeated follow-up examinations. These constraints have driven the development of advanced cardiac MRI techniques that aim to complement or, in selected contexts, extend beyond conventional LGE-based CE-CMR [6].

In recent years, advances in pulse sequence design, image acquisition, and post-processing have enabled the clinical application of parametric mapping techniques, myocardial deformation analysis using feature-tracking strain, and quantitative perfusion imaging. These techniques provide additional information on myocardial composition, function, and perfusion, allowing detection of diffuse fibrosis, edema, and microvascular ischemia that may not be apparent on standard LGE images. From a radiodiagnostic perspective, these developments represent a shift from predominantly visual assessment toward more objective and quantitative myocardial characterization [7].

Although advanced cardiac MRI techniques beyond LGE have demonstrated promising diagnostic and prognostic value in ischemic heart disease, their integration into routine CE-CMR protocols remains inconsistent. Many published studies focus on individual techniques in isolation and are characterized by heterogeneity in acquisition parameters, post-processing methods, and reported diagnostic thresholds. Consequently, the incremental value of advanced techniques beyond conventional CE-CMR has not been uniformly defined across different clinical scenarios [8].

There is a clear need for a focused, radiodiagnosis-oriented synthesis of current evidence that clarifies how advanced cardiac MRI techniques can be integrated with LGE-based CE-CMR, identifies their technical limitations and practical challenges, and outlines future directions for standardization and clinical translation. This review aims to address this gap by evaluating advanced cardiac MRI techniques beyond LGE in ischemic heart disease, emphasizing their technical principles, current evidence, and evolving role within contemporary CE-CMR practice.

Limitations of Conventional Contrast-Enhanced LGE Imaging in Ischemic Heart Disease

Contrast-enhanced cardiac magnetic resonance imaging (CE-CMR) using late gadolinium enhancement (LGE) has become the reference standard for noninvasive detection of myocardial infarction and replacement fibrosis in ischemic heart disease. The technique provides excellent spatial resolution and strong histopathologic correlation, allowing precise delineation of infarct location, size, and transmural extent. These characteristics underpin its widespread clinical adoption for viability assessment, risk stratification, and prognostic evaluation in patients with coronary artery disease [9].

Despite these strengths, conventional LGE-based CE-CMR is intrinsically limited by its reliance on relative signal intensity differences between abnormal and reference myocardium. This dependency makes LGE insensitive to diffuse interstitial fibrosis,

in which global expansion of the extracellular space occurs without a normal reference region for comparison. In such settings, myocardial signal intensity may appear uniformly nulled, leading to underestimation or complete non-detection of clinically relevant disease processes, particularly in patients with chronic ischemic cardiomyopathy [10].

Another important limitation of LGE imaging is its reduced ability to detect early ischemic injury and potentially reversible myocardial abnormalities. LGE primarily reflects irreversible myocardial damage associated with cell membrane rupture or collagenous scar formation. As a result, ischemic myocardium characterized by edema, metabolic derangement, or microvascular dysfunction without established fibrosis may not demonstrate enhancement, despite being pathophysiologically abnormal and clinically relevant [11].

From a technical standpoint, LGE image quality and diagnostic accuracy are influenced by several acquisition-related factors, including inversion time selection, heart rate variability, arrhythmias, and patient breath-holding capability. Inadequate myocardial nulling can reduce contrast between normal and abnormal myocardium, while motion artifacts may obscure small or subendocardial infarcts. These limitations are particularly relevant in patients with advanced heart failure or atrial fibrillation, who commonly undergo CE-CMR for ischemic evaluation [12].

Dependence on gadolinium-based contrast agents represents an additional constraint of conventional CE-CMR. Although modern contrast agents have a favorable safety profile, their use may be restricted in patients with advanced renal dysfunction or in those requiring repeated follow-up examinations. Moreover, increasing awareness of gadolinium deposition in extracardiac tissues has further motivated interest in contrast-sparing or contrast-free imaging approaches that can complement or partially substitute LGE imaging [13].

Finally, LGE imaging provides limited functional information. While it accurately depicts myocardial scar burden, it does not directly assess myocardial mechanics, perfusion reserve, or microvascular integrity. Consequently, LGE alone may not fully explain the degree of left ventricular dysfunction or symptoms in patients with ischemic heart disease, underscoring the need for complementary imaging techniques that extend beyond scar visualization [14].

Collectively, these limitations highlight the need for advanced cardiac MRI techniques that can augment conventional CE-CMR by providing quantitative, contrast-independent, and functionally relevant information. Understanding these shortcomings is essential for appreciating the clinical rationale behind the development and integration of advanced imaging methods beyond LGE in ischemic heart disease.

Native T1 and T2 Mapping in Ischemic Heart Disease

Native T1 and T2 mapping techniques represent a major advancement in cardiac magnetic resonance imaging by enabling pixel-wise quantitative assessment of myocardial tissue properties without reliance on relative signal intensity differences or, in the case of native T1 mapping, exogenous contrast agents. In the context of ischemic heart disease, these techniques address several limitations of conventional contrast-enhanced CMR by allowing detection of diffuse and subtle myocardial abnormalities that may not be apparent on late gadolinium enhancement (LGE) imaging alone [15].

Native T1 mapping reflects a composite signal influenced by myocardial water content, fibrosis, and cellular composition. In ischemic myocardium, native T1 values are typically elevated due to increased free water content in acute ischemia or expansion of the extracellular space in chronic myocardial injury. Importantly, native T1 mapping allows identification of diffuse interstitial fibrosis in chronically ischemic myocardium, even when LGE images appear normal due to the absence of a reference region of healthy myocardium [16]. This capability is particularly relevant in patients with ischemic cardiomyopathy and global left ventricular remodeling.

T2 mapping is primarily sensitive to myocardial water content and is therefore a robust marker of myocardial edema. In acute ischemic injury, T2 values increase due to intracellular and interstitial edema, allowing differentiation between acute and chronic myocardial infarction when interpreted alongside LGE imaging. From a radiodiagnostic perspective, T2 mapping provides objective quantification of edema burden, overcoming the subjectivity and limited reproducibility associated with conventional T2-weighted imaging techniques [17].

In patients with acute coronary syndromes, combined native T1 and T2 mapping enables comprehensive tissue characterization by simultaneously identifying myocardial edema, necrosis, and infarct core. This multiparametric approach improves diagnostic confidence in equivocal cases, such as myocardial infarction with nonobstructive coronary arteries, where conventional imaging findings may be subtle or atypical. Furthermore, mapping techniques allow assessment of myocardial injury extent beyond visually apparent LGE, offering a more complete representation of ischemic damage [18].

From a technical standpoint, mapping techniques are less dependent on precise inversion time selection and are less susceptible to errors related to myocardial nulling, which commonly affect LGE imaging. However, mapping values are influenced by scanner hardware, field strength, pulse sequence design, and post-processing algorithms, necessitating local reference ranges and careful standardization. These factors currently limit direct comparison across institutions and underscore the importance of protocol harmonization in clinical practice [19].

Clinically, native T1 and T2 mapping are increasingly used as complementary tools rather than replacements for contrast-enhanced CMR. When integrated with LGE, cine imaging, and perfusion assessment, mapping techniques enhance the diagnostic yield of CE-CMR by providing quantitative, contrast-independent information that improves characterization of ischemic myocardial injury across different disease stages. As standardization efforts progress, these techniques are expected to play an expanding role in routine radiodiagnostic evaluation of ischemic heart disease [20].

Extracellular Volume Quantification and Diffuse Fibrosis in Ischemic Heart Disease

Extracellular volume (ECV) quantification is an extension of parametric mapping techniques that provides a quantitative measure of myocardial extracellular matrix expansion. Derived from native and post-contrast T1 mapping in conjunction with hematocrit values, ECV reflects the proportion of myocardial tissue occupied by the extracellular space. In ischemic heart disease, ECV mapping enables detection and quantification of diffuse interstitial fibrosis that may not be visualized by conventional late gadolinium enhancement (LGE) imaging, particularly in the absence of focal scar [21].

Pathophysiologically, chronic myocardial ischemia leads to progressive myocyte loss, collagen deposition, and extracellular matrix remodeling, even in regions without prior transmural infarction. This diffuse fibrotic process contributes to ventricular stiffening, impaired contractility, and adverse remodeling. ECV mapping provides a sensitive and reproducible marker of these changes, allowing assessment of myocardial remodeling across the entire left ventricle rather than being limited to focal areas of enhancement [22].

From a radiodiagnostic standpoint, ECV quantification offers important incremental value over LGE-based contrast-enhanced CMR. While LGE excels at identifying replacement fibrosis, it underestimates diffuse fibrosis due to its reliance on relative signal intensity differences. ECV mapping overcomes this limitation by providing absolute quantitative values that can be compared across myocardial segments and over time, facilitating longitudinal assessment and treatment monitoring in patients with ischemic cardiomyopathy [23].

Clinical studies have demonstrated that elevated ECV values in ischemic heart disease are associated with worse left ventricular function, adverse remodeling, and poorer clinical outcomes. In patients with chronic coronary artery disease, ECV has been shown to identify myocardial involvement beyond visually apparent infarct regions, suggesting that diffuse fibrosis contributes significantly to global ventricular dysfunction. These findings support the role of ECV as a complementary biomarker to LGE within comprehensive contrast-enhanced CMR protocols [24].

Despite its advantages, ECV quantification has important technical and practical considerations. Accurate ECV measurement requires standardized acquisition of native and post-contrast T1 maps, appropriate timing after contrast administration, and reliable hematocrit measurement. Variability in pulse sequences, field strength, and post-processing algorithms can influence absolute ECV values, emphasizing the need for local reference ranges and standardized protocols to ensure reproducibility and clinical reliability [25].

In contemporary practice, ECV mapping is best viewed as an adjunct rather than a replacement for conventional LGE imaging. When integrated into multiparametric contrast-enhanced CMR examinations, ECV quantification enhances myocardial tissue characterization by capturing both focal replacement fibrosis and diffuse interstitial remodeling. As standardization efforts continue and evidence accumulates, ECV mapping is expected to play an increasingly important role in the radiodiagnostic evaluation and risk stratification of patients with ischemic heart disease [26].

Myocardial Strain and Deformation Imaging by Cardiac MRI

Myocardial deformation imaging has gained increasing importance as an adjunct to conventional functional assessment in ischemic heart disease. While left ventricular ejection fraction provides a global metric of systolic performance, it may not capture subtle or regionally heterogeneous myocardial dysfunction that is clinically relevant in coronary artery disease and ischemic cardiomyopathy. Cardiac MRI–derived strain offers a more sensitive characterization of myocardial mechanics and can be obtained without contrast administration when using feature-tracking methods applied to routine cine imaging [27].

Feature-tracking cardiac MRI derives strain parameters by tracking myocardial features across the cardiac cycle on balanced steady-state free precession cine images. This approach enables estimation of global longitudinal strain, circumferential strain, and radial strain without additional dedicated tagging sequences. From a radiodiagnostic standpoint, feature tracking is attractive because it can be integrated into standard CMR workflows with minimal additional scanning time, expanding functional characterization beyond conventional volumetric metrics [28].

In ischemic heart disease, myocardial strain measurements provide incremental information regarding the functional consequence of scar and diffuse myocardial remodeling. Strain abnormalities frequently extend beyond visually apparent infarct regions, reflecting compensatory remodeling, tethering effects, or microvascular dysfunction. Studies evaluating the relationship between strain and late gadolinium enhancement have demonstrated that strain impairment correlates with scar extent and heterogeneity, supporting its role as a functional marker that complements structural tissue characterization [29].

Prognostically, feature-tracking global longitudinal strain has shown strong associations with adverse outcomes, including mortality, in both ischemic and nonischemic cardiomyopathy populations. Importantly, strain may provide risk stratification beyond ejection fraction alone, particularly in patients with moderately reduced ejection fraction or in those with discordance between symptoms, scar burden, and global systolic function. From a clinical imaging perspective, this expands the value of CMR beyond diagnosis into multiparametric prognostication [30].

Practical limitations of strain imaging include variability in vendor software, differences in tracking algorithms, and dependence on cine image quality. Arrhythmia, respiratory motion, and inadequate temporal resolution can reduce tracking accuracy. Standardization remains a major barrier to widespread clinical adoption, and reporting of strain metrics requires careful attention to local reference ranges and reproducibility. These considerations parallel challenges faced by mapping techniques and support the need for harmonized acquisition and analysis pathways [31].

In contemporary radiodiagnostic practice, myocardial strain is best applied as a complementary parameter within comprehensive contrast-enhanced CMR protocols. When interpreted alongside cine function, LGE scar distribution, and mapping markers of diffuse fibrosis, strain provides an additional layer of information regarding myocardial mechanics and risk. As evidence grows and standardization improves, deformation imaging is expected to become an increasingly routine component of advanced cardiac MRI assessment in ischemic heart disease [32].

Stress Perfusion CMR and Quantitative Myocardial Blood Flow Mapping

Stress perfusion CMR is a core component of contrast-enhanced CMR (CE-CMR) for ischemic heart disease because it directly interrogates inducible ischemia through first-pass gadolinium dynamics under vasodilator stress. Unlike LGE, which primarily depicts irreversible injury, stress perfusion CMR evaluates physiologic consequences of coronary stenosis and microvascular dysfunction, and it can be integrated with cine and LGE into a single exam for combined assessment of function, ischemia, and scar [33].

Conventional stress perfusion interpretation in clinical practice is most commonly qualitative or semi-quantitative, relying on the presence of reversible subendocardial or transmural perfusion defects that appear during stress and resolve at rest. This approach is widely validated and clinically useful, but it can be limited in multivessel disease and balanced ischemia where relative differences between myocardial territories may be blunted, potentially leading to under-recognition of global ischemic burden when visual assessment is the only method applied [34].

To address these limitations, quantitative stress perfusion CMR techniques have evolved to estimate absolute myocardial blood flow and myocardial perfusion reserve, moving beyond relative “defect-based” interpretation. Quantitative mapping improves detection of diffuse or balanced ischemia and provides objective physiologic parameters that can be tracked over time or compared across myocardial regions. From a radiodiagnostic perspective, quantitative perfusion is a key step toward reproducible, threshold-based reporting that aligns with the broader shift toward quantitative CMR paradigms [35].

Quantitative perfusion CMR has also become increasingly important in characterizing coronary microvascular dysfunction, particularly in patients with angina symptoms and nonobstructive or mildly obstructive coronary disease. In these patients, global reductions in perfusion reserve may explain symptoms and risk, while LGE may be absent or minimal. This expands the clinical utility of CE-CMR beyond obstructive epicardial CAD into microvascular phenotypes where ischemia is physiologic rather than purely anatomic [36].

Technical pitfalls remain a critical consideration for radiology-led interpretation. The endocardial dark rim artifact is a common confounder that can mimic subendocardial ischemia, and image quality may be degraded by arrhythmia, poor breath-holding, or

inadequate temporal resolution. These limitations apply to both qualitative and quantitative approaches and reinforce the need for careful acquisition design, artifact recognition, and standardized interpretation strategies when stress perfusion CMR is used for diagnostic and management decisions [33].

Clinically, the most effective CE-CMR workflow in ischemic heart disease is multiparametric: cine imaging establishes function, stress perfusion identifies inducible ischemia, and LGE defines scar substrate. Within this framework, quantitative perfusion mapping is emerging as a practical enhancement that improves confidence in multivessel disease and microvascular dysfunction and supports more objective longitudinal evaluation as advanced analysis tools mature and become more widely available [37].

echnical Innovations Refining CE-CMR Beyond Conventional LGE

Several technical innovations have been developed to improve the diagnostic performance and robustness of contrast-enhanced CMR (CE-CMR) beyond conventional bright-blood LGE, particularly for clinically important scenarios such as subtle subendocardial infarction, arrhythmia, and imperfect myocardial nulling. From a radiodiagnostic perspective, these developments are best understood as refinements that improve contrast, reduce reader variability, and strengthen interpretability rather than replacing LGE as the foundational scar technique [38].

Phase-sensitive inversion recovery (PSIR) represents a key advance in LGE imaging because it reduces dependence on exact inversion time selection by preserving signal polarity information. This improves consistency of myocardial nulling across patients and time points after contrast injection, especially when contrast kinetics vary or when repeated TI scouting is impractical. In routine practice, PSIR can reduce false-negative and false-positive interpretation related to suboptimal nulling and is particularly helpful in complex or high-throughput workflows [39].

Conventional bright-blood LGE can be limited by poor scar-to-blood contrast, most notably for thin subendocardial infarcts where enhancement may blend with the blood pool. Dark-blood LGE techniques address this by suppressing blood pool signal while maintaining conspicuity of enhanced myocardium, improving detection of subendocardial scar and strengthening confidence in transmurality grading. This has direct clinical relevance in ischemic heart disease where small subendocardial infarcts can alter diagnosis, risk stratification, and treatment planning [40].

Evidence supporting dark-blood approaches includes studies demonstrating improved visualization and diagnostic performance for subendocardial infarction compared with conventional bright-blood LGE. For radiologists, the practical value is in reducing “borderline calls” and minimizing under-recognition of ischemic scar, especially in patients with small infarcts, limited wall thickness, or suboptimal conventional contrast relationships [41].

High-resolution LGE strategies and contemporary motion-robust implementations are also increasingly used to address common real-world acquisition challenges. These methods aim to reduce partial-volume effects, improve depiction of scar heterogeneity, and maintain image quality in patients with arrhythmia or limited breath-holding. Technical reviews emphasize that these improvements are most effective when integrated into standardized CE-CMR protocols, with attention to gating strategy, spatial resolution, and quality control during acquisition [42].

Finally, the value of these innovations depends on consistent protocol execution and reporting. Standardized CE-CMR protocols provide the framework within which PSIR, dark-blood LGE, and high-resolution approaches can be applied reproducibly, and structured reporting ensures that improved image quality translates into clinically actionable interpretations. From a radiodiagnosis standpoint, technical refinement and reporting discipline are inseparable in maximizing the clinical impact of advanced CE-CMR [43].

Integration of Advanced Techniques into Clinical CE-CMR Workflows and Future Directions

The expanding portfolio of advanced cardiac MRI techniques necessitates thoughtful integration into routine contrast-enhanced CMR (CE-CMR) workflows to ensure clinical feasibility, diagnostic value, and consistency. In ischemic heart disease, the challenge for radiologists is not the availability of techniques, but rather selecting and combining appropriate sequences to answer specific clinical questions without excessively prolonging scan time or compromising image quality [44].

A pragmatic multiparametric CE-CMR approach typically begins with cine imaging for assessment of ventricular volumes and global and regional function, followed by stress perfusion imaging when ischemia evaluation is indicated, and late gadolinium enhancement (LGE) for scar characterization. Advanced techniques such as native T1/T2 mapping, extracellular volume quantification, and myocardial strain analysis can be selectively incorporated based on the clinical scenario, for example in patients with suspected diffuse fibrosis, equivocal LGE findings, or disproportionate ventricular dysfunction [45].

From a radiodiagnostic perspective, protocol tailoring is essential. Not all patients require every advanced technique, and indiscriminate protocol expansion may reduce throughput and increase susceptibility to motion and fatigue-related artifacts. Instead, advanced techniques should be used to address specific diagnostic gaps left by conventional CE-CMR, such as detection of diffuse interstitial fibrosis, differentiation of acute versus chronic injury, or evaluation of microvascular ischemia in the absence of obstructive coronary disease [46].

Standardization of acquisition and reporting is critical for successful clinical integration. Variability in scanner hardware, pulse sequence implementation, and post-processing algorithms can significantly influence quantitative values derived from mapping, strain, and perfusion techniques. Adoption of standardized CE-CMR protocols and structured reporting frameworks helps ensure reproducibility, facilitates longitudinal follow-up, and improves communication between radiologists and referring clinicians [47].

Looking forward, continued technical refinement and validation will determine the future role of advanced CE-CMR techniques in ischemic heart disease. Areas of active development include faster acquisition strategies, motion-robust imaging, improved spatial resolution, and harmonization of quantitative metrics across vendors and field strengths. As these challenges are addressed, advanced techniques are likely to transition from specialized tools into routine components of comprehensive CE-CMR examinations [48].

Ultimately, the future of cardiac MRI in ischemic heart disease lies in a balanced, problem-oriented approach that leverages the strengths of both conventional LGE imaging and advanced quantitative techniques. By integrating these methods thoughtfully within clinical workflows, CE-CMR can continue to evolve as a central, precision imaging modality for diagnosis, risk stratification, and management of ischemic heart disease [49].

Conclusion

Advanced cardiac magnetic resonance imaging techniques have significantly expanded the diagnostic capabilities of contrast-enhanced CMR in ischemic heart disease beyond conventional late gadolinium enhancement. While LGE remains the cornerstone for detection and quantification of myocardial infarction and replacement fibrosis, it provides an incomplete representation of the complex pathophysiology underlying ischemic myocardial injury and remodeling. Emerging quantitative approaches, including parametric mapping, extracellular volume assessment, myocardial deformation imaging, and refined perfusion analysis, address important diagnostic gaps by enabling detection of diffuse fibrosis, myocardial edema, microvascular dysfunction, and subtle functional impairment.

From a radiodiagnostic perspective, the greatest strength of advanced cardiac MRI lies in its multiparametric nature. When thoughtfully integrated into contrast-enhanced CMR workflows, advanced techniques complement rather than replace conventional imaging, enhancing diagnostic confidence and clinical relevance. Selective, problem-oriented application of these methods allows radiologists to tailor examinations to specific clinical questions while maintaining feasibility and image quality in routine practice. Despite growing evidence supporting their clinical utility, challenges related to standardization, reproducibility, and workflow integration persist. Continued technical refinement, harmonization of acquisition and analysis protocols, and close collaboration between radiologists, cardiologists, and imaging societies will be essential to translate advanced techniques into widespread clinical use. As these barriers are addressed, advanced cardiac MRI is poised to play an increasingly central role in precision imaging of ischemic heart disease, offering comprehensive, noninvasive characterization of myocardial structure, function, and perfusion within a single examination.

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