Review

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Review

Clinical Advances in Extracellular Volume Measurement by Cardiac Computed Tomography and Magnetic Resonance Imaging: Current Status and Future Perspectives

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Abstract

The myocardial extracellular volume (ECV) has emerged as a critical biomarker for diagnosing and managing cardiac disease, as it reflects changes in myocardial tissue composition such as fibrosis and edema. Cardiac magnetic resonance imaging (MRI) and computed tomography (CT) have increasingly been used to non-invasively quantify ECV, providing valuable insights into myocardial pathology. This review summarizes the latest advancements in ECV measurement techniques using cardiac CT and MRI, emphasizing their clinical applications in conditions including cardiomyopathies, myocardial fibrosis, and heart failure. We discuss the technical principles underlying ECV quantification via both imaging modalities, compare their diagnostic accuracy and reproducibility, and highlight the complementary roles they play in clinical practice. Challenges such as standardization, radiation exposure in CT, and contrast agent considerations are also addressed. By analyzing current literature, we provide an overview of the consistency and discrepancies between CT- and MRI-derived ECV measurements, and propose future directions for improving imaging protocols, expanding clinical indications, and integrating ECV assessment into personalized treatment strategies. This comprehensive review aims to inform clinicians and researchers about the evolving role of ECV quantification in cardiac imaging and its potential to enhance cardiovascular disease diagnosis and management.

Keywords: cardiac computed tomography; cardiac magnetic resonance imaging; extracellular volume; cardiovascular disease; clinical application

1. Introduction

The extracellular volume (ECV) fraction, which represents the proportion of myocardial tissue occupied by the extracellular matrix (ECM) and interstitial space, has emerged as a key biomarker for assessing cardiac tissue pathology, particularly myocardial fibrosis. Myocardial fibrosis, characterized by excessive collagen deposition and ECM remodeling, plays a significant role in the pathophysiology of various cardiac diseases, including cardiomyopathies, ischemic injury, infiltrative disorders, and inflammatory conditions. Since fibrosis adversely affects myocardial compliance, electrical conduction, and contractile function, accurate quantification of ECV provides critical insights into disease severity, prognosis, and therapeutic response. Cardiac magnetic resonance imaging (MRI), particularly with parametric mapping techniques such as T1 mapping and late gadolinium enhancement (LGE), is conventionally the clinical gold standard for non-invasive ECV quantification and myocardial tissue characterization [PMID: 38595125, 39867184]. T1 mapping enables the quantification of diffuse interstitial fibrosis by calculating native and post-contrast T1 relaxation times, while LGE identifies focal replacement fibrosis. The ECV fraction derived from these measurements strongly correlates with histopathological fibrosis and predicts adverse outcomes in heart failure (HF) and cardiomyopathies [PMID: 38595125, 39867184]. MRI-derived ECV (MRI-ECV) quantification has shown clinical utility in diverse conditions, including hypertensive heart disease, cardiac amyloidosis (CA), dilated cardiomyopathy (DCM), and inflammatory myocarditis, serving as a robust tool for early diagnosis and risk stratification [PMID: 32890280, 33067004, 39867184, 40102107]. Despite its superior tissue characterization capabilities, cardiac MRI has inherent limitations. It requires patient cooperation for breath-holding, is contraindicated in patients with certain implanted devices or severe claustrophobia, and is less accessible in some clinical settings due to cost and availability constraints. These factors have stimulated interest in alternative imaging modalities capable of ECV assessment with broader clinical applicability.

Cardiac computed tomography (CT) has rapidly evolved from a primarily coronary artery imaging tool to a versatile modality capable of myocardial tissue characterization, including ECV quantification. Advances in CT technology, such as dual-energy CT (DECT), single-energy CT (SECT) with iodine density imaging, and the emerging photon-counting detector CT (PCD-CT), have enhanced spatial resolution and contrast differentiation, enabling the non-invasive detection of myocardial fibrosis and calculation of ECV [PMID: 40137579, 39963992, 40774023]. CT-derived ECV (CT-ECV) measurement leverages the differential distribution of iodinated contrast agents between the intravascular and interstitial spaces, analogous to gadolinium-based methods in MRI. Many studies have shown a strong correlation between CT-ECV and MRI-ECV values across various cardiac pathologies, including CA, aortic stenosis (AS), pulmonary hypertension, and myocarditis, underscoring the diagnostic and prognostic value of CT-ECV [PMID: 40142874, 37597032, 35661458, 40102107]. Importantly, CT provides several practical advantages such as shorter acquisition times, fewer contraindications, and the ability to simultaneously evaluate the coronary artery, which may streamline patient assessment and improve clinical workflow [PMID: 39963992, 40137579]. The development of PCD-CT, with superior spectral resolution and noise reduction, has shown promise in enhancing the accuracy and reproducibility of myocardial ECV quantification, particularly in patients with elevated heart rates or arrhythmias, where conventional CT techniques may be limited [PMID: 40903622, 36719292]. Despite these technological advances, challenges persist in standardizing CT protocols, minimizing radiation exposure, and validating CT-ECV against histopathological standards and clinical outcomes in larger, multicenter cohorts.

Given the complementary strengths and limitations of cardiac MRI and CT, a growing body of literature focuses on delineating their respective roles in clinical practice and exploring the potential of CT as a viable alternative or adjunct to MRI for ECV assessment. While MRI remains the gold standard, the expanding capabilities of CT provide a practical solution for patients contraindicated for MRI or requiring comprehensive coronary and myocardial evaluation in a single session [PMID: 40142874, 39963992]. Moreover, emerging techniques such as non-contrast myocardial tissue composition mapping using advanced MRI sequences and multiparametric CT imaging are poised to further refine the detection and quantification of myocardial fibrosis, facilitating earlier diagnosis and tailored therapeutic strategies [PMID: 40501284, 39963992]. This review aims to provide a comprehensive overview of the current clinical applications of cardiac CT- and MRI-ECV quantification, highlighting recent technological innovations, comparative diagnostic performance, and prognostic implications. Furthermore, it discusses future perspectives, including the integration of artificial intelligence (AI) and machine learning for enhanced image analysis, the role of novel tracers and imaging biomarkers, and the potential for personalized medicine approaches in cardiovascular care. We seek to elucidate the evolving landscape of ECV imaging through this synthesis, guiding clinicians and researchers in optimizing the use of cardiac CT and MRI for improved patient outcomes.

2. Main Body

2.1. Definition of the Extracellular Volume (ECV) and Its Clinical Significance

2.1.1. Physiological Basis of ECV

The ECV represents the fraction of myocardial tissue volume that lies outside the cardiomyocytes, encompassing the interstitial space, ECM, vascular compartment, and interstitial fluid. Physiologically, the ECV is primarily composed of water; electrolytes such as sodium and chloride; structural proteins including collagen, elastin, and proteoglycans; and various signaling molecules. This compartment plays a crucial role in maintaining myocardial structural integrity, facilitating nutrient and waste exchange, and modulating cellular signaling. The dynamic balance between intracellular and extracellular compartments is essential for normal cardiac function, with ECV values typically ranging from 20% to 30% in healthy myocardium, as measured by cardiac MRI techniques [1,2].

Cardiomyocyte size and density influence both the size and composition of the ECV. Studies in healthy porcine models have shown a negative correlation between cardiomyocyte breadth and ECV, indicating that larger cardiomyocytes occupy more intracellular space, thereby reducing the relative extracellular fraction [1]. Sex differences also contribute to variations in ECV, with females exhibiting higher myocardial perfusion, blood volume, and ECV than males, suggesting intrinsic physiological differences in myocardial extracellular composition and vascularization [2,3]. Furthermore, the ECV is modulated by hematocrit levels and myocardial blood volume, reflecting the interplay between vascular and interstitial compartments.

The ECV expansion is a hallmark of myocardial remodeling in pathological states, particularly in the context of fibrosis, inflammation, and edema. Myocardial fibrosis involves excessive deposition of ECM components, particularly collagen, leading to increased ECV and altered mechanical properties of the myocardium. This expansion can be diffuse or focal and is associated with impaired ventricular compliance and function [4,5]. For instance, increased sympathetic nerve activity correlates with expanded ECV in hypertensive heart disease, indicating early interstitial fibrosis [5]. Similarly, ECV in CA elevation reflects amyloid infiltration and correlates with microvascular dysfunction and myocardial stiffening [6].

The ECM within the ECV is not merely a passive scaffold but actively modulates cellular behavior through biochemical and mechanical signaling. Its composition and cross-linking, mediated by enzymes such as lysyl oxidase, influence myocardial stiffness and remodeling processes [7]. Moreover, the ECV contains extracellular vesicles (ECVs), which are membrane-bound particles involved in intercellular communication and carry molecular cargoes that can influence cardiac physiology and pathology [8]. These vesicles contribute to the pathogenesis of various cardiac conditions by mediating signaling pathways that regulate fibrosis, inflammation, and repair.

Water and sodium homeostasis within the ECV are tightly regulated to maintain osmotic balance and volume status, which are critical for cardiac function. The kidney and heart coordinate to regulate extracellular fluid volume and composition, with disturbances leading to conditions such as HF and cardiorenal syndrome [9,10]. Sodium concentration within the ECV influences cell volume regulation and myocardial stiffness, with abnormal sodium handling implicated in hypertension and cardiac remodeling [11,12]. Aquaporins and ion channels modulate transmembrane water and ion fluxes, affecting cardiomyocyte volume and extracellular fluid dynamics [13].

In summary, the physiological basis of ECV encompasses its composition of interstitial fluid, ECM, vascular elements, and ECVs, all of which contribute to myocardial structure and function. Alterations in ECV size and composition both reflect and influence cardiac pathology, particularly through mechanisms involving fibrosis, inflammation, and volume dysregulation. Advanced imaging modalities such as cardiac MRI T1 mapping enable non-invasive quantification of ECV, providing insights into myocardial health and disease progression [12]. Therefore, understanding the physiological and pathological roles of ECV is essential for interpreting its clinical significance in cardiac imaging and for developing targeted therapies aimed at modulating ECM remodeling and myocardial stiffness.

2.1.2. ECV and Its Association with Cardiac Diseases

ECV quantification has emerged as a pivotal biomarker in evaluating myocardial tissue remodeling across various cardiac diseases, including HF, cardiomyopathies, and infiltrative disorders. Additionally, ECV reflects myocardial ECM expansion, predominantly due to fibrosis or infiltration, and can be non-invasively measured using cardiac MRI or CT. Multiple studies have shown that increased myocardial ECV is strongly associated with adverse clinical outcomes and provides incremental prognostic information beyond conventional imaging parameters.

Both preserved and reduced ejection fraction phenotypes in HF populations exhibit elevated ECV values, which correlate with myocardial fibrosis burden and predict hospitalization and mortality. A large cardiac MRI cohort study demonstrated that both higher ECV and indexed ECV were independently associated with HF hospitalization and death, even after adjusting for age, sex, left ventricular function, and biomarkers such as N-terminal pro-brain natriuretic peptide (NT-proBNP) [14]. ECV also correlates with myocardial strain parameters, such as global longitudinal strain (GLS). However, these two metrics represent distinct pathophysiological domains—ECV and GLS reflecting interstitial expansion and contractile function, respectively—with minimal correlation but additive prognostic value [15]. This suggests that combining ECV and strain imaging enhances risk stratification in HF.

ECV quantification in cardiomyopathies provides critical insights into disease severity and progression. Patients with hypertrophic cardiomyopathy (HCM) exhibit increased ECV, which correlates with adverse remodeling, arrhythmic risk, and major adverse cardiovascular events (MACEs). A multicenter prognosis study demonstrated that ECV and epicardial adipose tissue volume index measured by cardiac MRI were strong predictors of MACEs in HCM, improving risk stratification [16]. Similarly, elevated ECV in DCM and other non-ischemic cardiomyopathies reflects diffuse interstitial fibrosis and is associated with impaired ventricular function and worse outcomes [17]. In rare genetic cardiomyopathies such as Danon disease and Friedreich’s ataxia, increased ECV measured by cardiac MRI has been shown to reflect the extent of myocardial fibrosis and correlates with disease severity and ventricular remodeling [18,19].

ECV also plays a crucial role in the evaluation of infiltrative cardiac diseases, notably CA. Quantitative ECV measurements strongly correlate with amyloid burden and functional impairment. In wild-type transthyretin amyloid cardiomyopathy, ECV has been shown to correlate with cardiac biomarkers (NT-proBNP and troponin T), longitudinal strain, exercise capacity, and disease stage, providing a comprehensive assessment of disease severity [20]. CT-ECV has shown high diagnostic accuracy for CA, with sensitivity and specificity exceeding 85%, facilitating its utility for non-invasive diagnosis and preoperative planning for transcatheter aortic valve replacement (TAVR) [21]. Moreover, ECV quantification can monitor treatment response in amyloidosis, as demonstrated by serial cardiac MRI studies showing reductions in ECV after chemotherapy and stem cell transplantation [22].

In systemic diseases with cardiac involvement—such as systemic sclerosis (SSc), granulomatosis with polyangiitis (GPA), and immune-mediated inflammatory diseases (IMIDs)—elevated myocardial ECV reflects subclinical myocardial fibrosis and microvascular pathology, both of which are linked to disease severity and adverse outcomes. For example, higher ECV and LGE in SSc are associated with skin score, digital ulcers, and biomarkers of myocardial injury, indicating early cardiac involvement despite preserved systolic function [23,24]. Similarly, increased ECV in GPA correlates with disease phenotype, antineutrophil cytoplasmic antibody status, and myocardial fibrosis detected by LGE [25]. Systemic sclerosis has emerged as a major determinant of myocardial fibrosis in IMIDs, with smoking and body mass index also influencing ECV levels [26].

Diabetes mellitus, particularly type II diabetes, is associated with increased myocardial ECV, reflecting diffuse interstitial fibrosis that contributes to diabetic cardiomyopathy and HF risk. Studies have shown that patients with diabetes accompanied by complications exhibit significantly higher ECV than those without, and elevated ECV independently predicts adverse cardiovascular events [27,28]. Furthermore, sodium-glucose cotransporter 2 inhibitors, which are known to reduce cardiovascular mortality in diabetes, may exert beneficial effects on myocardial remodeling, potentially modulating ECV and fibrosis [29,30].

In patients undergoing cardiac interventions such as TAVR, elevated pre-procedural ECV predicts the development of conduction abnormalities and the need for permanent pacemaker implantation, underscoring the clinical utility of ECV in procedural risk stratification [31]. Additionally, ECV and myocardial strain parameters in hypertensive heart disease serve as sensitive markers for myocardial abnormalities and treatment response, with ECV reflecting interstitial fibrosis that contributes to ventricular remodeling [32].

Emerging evidence supports the feasibility and prognostic value of CT-ECV measurements, which demonstrate strong correlation with cardiac MRI-ECV and histopathology. CT-ECV provides advantages in availability, cost, and applicability in patients contraindicated for MRI, thereby expanding the clinical utility of myocardial fibrosis assessment [33,35]. Moreover, novel CT techniques, including PCD-CT, enable the simultaneous assessment of coronary artery disease and myocardial ECV in infiltrative diseases such as amyloidosis [36].

In summary, myocardial ECV quantification is a robust, non-invasive biomarker that reflects diffuse interstitial fibrosis and infiltration, providing critical diagnostic and prognostic information across various cardiac diseases. Its integration with functional imaging and serum biomarkers enhances risk stratification, guides therapeutic decision-making, and facilitates the monitoring of disease progression and treatment response. Ongoing advancements in imaging technology, coupled with the standardization of ECV measurement protocols, will further consolidate its role in precision cardiovascular medicine.

2.2. Advantages of Magnetic Resonance Imaging (MRI) in ECV Measurement

2.2.1. MRI Technology Overview

Over the past three decades, MRI has evolved from an experimental technique to a routine, indispensable tool in cardiac diagnostics, providing unparalleled spatial and temporal resolution for myocardial function and tissue characterization [37]. Among the various MRI techniques, T1 mapping has emerged as a pivotal method for quantifying myocardial tissue properties, particularly the ECV fraction, which serves as a biomarker of interstitial expansion due to fibrosis, edema, or infiltration [38]. The principle of T1 mapping is based on acquiring multiple images at varying inversion times or flip angles to generate pixel-wise maps of the longitudinal relaxation time (T1) of myocardial tissue. Native (pre-contrast) T1 values reflect intrinsic tissue characteristics, whereas post-contrast T1 values, combined with hematocrit levels, enable ECV calculation by quantifying the distribution volume of gadolinium-based contrast agents within the extracellular space [39].

The use of T1 mapping in ECV measurement is particularly valuable because it enables non-invasive, quantitative assessment of diffuse myocardial fibrosis that may be undetectable by conventional LGE imaging, which primarily identifies focal scar [38]. This quantitative approach enhances diagnostic accuracy in various cardiomyopathies, including dilated, hypertrophic, and infiltrative forms such as amyloidosis and Fabry disease, by detecting subtle interstitial changes before the development of overt structural abnormalities [40,41]. For example, native T1 mapping can differentiate between Fabry disease and amyloidosis without contrast administration, whereas ECV quantification provides a direct measure of ECM expansion [40]. Additionally, T1 mapping has prognostic implications. Elevated ECV correlates with adverse outcomes such as arrhythmias and sudden cardiac death, emphasizing its clinical relevance [42].

Technically, T1 mapping sequences have been refined to improve accuracy and reproducibility. The modified Look-Locker inversion recovery (MOLLI) and shortened MOLLI are commonly used sequences that balance acquisition time and precision [38]. They can be performed during breath-hold or with respiratory compensation techniques to mitigate motion artifacts, a persistent challenge in cardiac MRI [43]. Recent advances, including free-breathing T1 mapping with ultrasound-driven slice tracking, have further enhanced image quality and patient comfort [43]. Furthermore, post-processing algorithms facilitate pixel-wise T1 calculation, enabling detailed regional myocardial characterization.

The clinical utility of T1 mapping extends beyond diagnosis to treatment monitoring. For instance, changes in ECV measured by T1 mapping in CA correlate with histological amyloid load and response to therapies such as tafamidis [44,45]. Similarly, combined T1 and T2 mapping improves early detection of myocardial damage in DCM by revealing both fibrotic and edematous changes [46]. T1 mapping-derived ECV predicts adverse outcomes in heart transplant patients, underscoring its role in surveillance [47].

Taken together, T1 mapping is a robust MRI technique that quantitatively assesses myocardial tissue characteristics by measuring T1 relaxation times pre- and post-contrast administration. Its application in ECV measurement provides a sensitive and non-invasive biomarker of myocardial fibrosis and interstitial disease, thereby enhancing diagnostic accuracy, guiding therapy, and informing prognosis across various cardiac pathologies [38,40]. Ongoing technological improvements continue to address challenges such as motion artifacts and acquisition time, paving the way for wider clinical adoption and improved patient care.

2.2.2. Examples of MRI Clinical Application

MRI-ECV fraction is a pivotal quantitative biomarker for assessing myocardial fibrosis and interstitial remodeling across various cardiac diseases. Numerous clinical studies have validated MRI-ECV for characterizing myocardial tissue alterations, correlating with histopathology, and predicting clinical outcomes. In DCM, combined T1 and T2 mapping with ECV quantification has shown superior diagnostic power compared with LGE alone. Specifically, native T1, T2, and ECV values were significantly higher in patients with DCM than in controls, with combined mapping achieving an area under the curve (AUC) of 0.96 for diagnosis, indicating enhanced sensitivity in detecting fibrotic and edematous myocardial changes at early disease stages [46]. Similarly, MRI-ECV correlates with myocardial amyloid burden and provides prognostic stratification in systemic light-chain amyloidosis. However, the presence of myocardial edema, as revealed by prolonged T2 relaxation times, may confound ECV measurements, necessitating multiparametric imaging approaches that integrate T1, T2, and LGE for accurate tissue characterization [48,49]. In HCM, PCD-CT-derived ECV (PCD-CT-ECV) has shown a strong correlation with MRI-ECV, and MRI-ECV quantification correlates with functional capacity and biomarkers such as NT-proBNP, underscoring its role in fibrosis assessment and risk stratification [50].

MRI-ECV has also been validated against histological collagen quantification in patients with aortic valve stenosis and HCM, demonstrating a strong correlation (r=0.70), confirming its reliability as a non-invasive surrogate for diffuse myocardial fibrosis [51]. In patients with atrial fibrillation (AF), MRI-ECV quantification is feasible and correlates well with CT-ECV, even in the presence of arrhythmia, supporting its clinical application in this population [52]. Moreover, elevated myocardial ECV and T2 mapping values independently predict adverse cardiac and non-cardiac outcomes in cardiac transplant recipients, highlighting their prognostic significance in graft monitoring [47].

In the context of cancer therapy-related cardiotoxicity, systematic reviews and meta-analyses have shown that MRI-ECV is significantly higher in patients exposed to cardiotoxic treatments than in controls, suggesting that ECV can detect subclinical myocardial changes prior to overt dysfunction [53]. Similarly, MRI-ECV has been shown to strongly correlate with histological collagen volume fraction in diabetic cardiomyopathy models, enabling early detection and monitoring of diffuse myocardial interstitial fibrosis [54].

MRI-ECV also plays a critical role in inflammatory cardiac diseases such as myocarditis. Studies employing advanced cardiac MRI techniques, including T1 mapping and LGE, have demonstrated higher ECV values in acute myocarditis than in normal myocardium, with thresholds yielding high diagnostic accuracy (AUC=0.95), thereby facilitating non-invasive diagnosis and disease monitoring

[55]. In post-acute sequelae of coronavirus disease 2019, multiparametric cardiac MRI, including ECV and strain imaging, has been shown to differentiate myocardial involvement, with reduced strain parameters correlating with increased ECV and T1 values, thereby reflecting myocardial injury and fibrosis [56].

Furthermore, MRI-ECV quantification facilitates early diagnosis, treatment response assessment, and risk stratification in rare cardiac pathologies such as CA. Meta-analyses indicate that ECV remains stable or decreases with effective therapy (e.g., tafamidis), while elevated ECV predicts MACE, outperforming traditional biomarkers [44,57]. In arrhythmogenic right ventricular cardiomyopathy, MRI-derived biventricular GLS and ECV provide incremental prognostic value beyond established risk scores for predicting sustained ventricular arrhythmias [58].

Overall, cardiac MRI-ECV measurement has demonstrated robust clinical applicability across various cardiac diseases, providing a quantitative assessment of myocardial fibrosis and interstitial changes that correlate with histology, functional impairment, and clinical outcomes. Its integration with complementary MRI techniques such as T1/T2 mapping, LGE, and strain imaging enhances diagnostic accuracy and prognostic stratification, supporting its expanding role in personalized cardiac care.

2.3. Advances in Computed Tomography (CT) for ECV Measurement

2.3.1. Evolution of CT Technology

The evolution of CT technology has profoundly influenced its clinical applications, particularly in cardiovascular imaging and ECV quantification. Initially, SECT was the primary modality for cardiac imaging, providing anatomical information with reasonable spatial and temporal resolution. It operates by acquiring images at a single X-ray energy spectrum, which limits its ability to differentiate materials with similar attenuation properties, such as iodine contrast and calcium, thereby constraining accurate tissue characterization and quantification of myocardial ECV. Over the past decades, advancements in hardware and software have improved the spatial and temporal resolution of SECT, enabling better visualization of coronary arteries and myocardial structures; however, challenges remain in functional assessment and radiation dose reduction [59,60].

Notably, the introduction of DECT marked a significant milestone in CT technology evolution, enabling the acquisition of images at two distinct energy spectra. This spectral imaging capability allows for material differentiation based on energy-dependent attenuation differences, facilitating improved tissue characterization, such as distinguishing iodine from calcium and more precisely quantifying myocardial ECV. DECT systems have evolved since their clinical introduction in 2006, with improvements in detector technology, acquisition speed, and post-processing algorithms enhancing image quality and diagnostic accuracy [61,62]. Its ability to perform material decomposition and generate iodine maps has been instrumental in myocardial tissue characterization and ECV measurement, providing functional insights beyond anatomical imaging.

More recently, PCD-CT has emerged as a promising advancement, providing ultra-high spatial resolution, improved contrast-to-noise ratio, and spectral imaging capabilities in a single acquisition. It detects individual photons and measures their energy, enabling precise spectral separation and material quantification while reducing radiation dose. This technology enhances the accuracy of myocardial ECV quantification by improving iodine signal detection and reducing artifacts, thereby refining myocardial tissue characterization [63,65]. Early clinical studies have demonstrated PCD-CT's potential to surpass DECT and SECT in cardiac imaging applications, including ECV assessment.

The progression from SECT to DECT and presently to PCD-CT reflects a trajectory toward more sophisticated imaging modalities that combine anatomical and functional assessment with improved image quality and lower radiation exposure. These technological evolutions have expanded CT's role in cardiovascular imaging from mere coronary artery visualization to comprehensive myocardial characterization, including ECV quantification. The integration of AI and advanced reconstruction algorithms further enhances the potential of these technologies to provide reliable, reproducible, and clinically relevant ECV measurements [60,66]. In summary, the development of CT technology from SECT to DECT and PCD-CT has progressively improved the capacity for accurate, non-invasive myocardial ECV quantification, paving the way for broader clinical applications and improved patient management.

2.3.2. CT Clinical Application Research

CT-ECV measurement has emerged as a promising non-invasive technique for myocardial tissue characterization, particularly in diseases such as myocarditis, HF, CA, and AS. Several studies have shown that CT-ECV strongly correlates with cardiac MRI-ECV, which remains the reference standard for myocardial fibrosis and interstitial expansion assessment. PCD-CT has been shown to accurately quantify myocardial ECV in acute myocarditis, with strong segmental correlations to MRI and excellent diagnostic performance. A study involving 32 patients with suspected myocarditis found no significant difference between CT-ECV and MRI-ECV values, and the CT-ECV value was significantly elevated in patients with MRI-confirmed myocarditis, yielding an AUC of 0.95 for diagnosis [55]. This highlights CT-ECV's potential as a non-invasive imaging biomarker for myocarditis evaluation.

CT-ECV has been validated as a risk stratification tool in HF. Using spectral detector CT, the CT-ECV value was significantly elevated in patients with non-ischemic HF compared with controls, with higher CT-ECV values correlating with worse New York Heart Association functional class and reduced left ventricular ejection fraction. Patients with CT-ECV of ≥31.29% reportedly had a higher probability of MACE [67]. Moreover, CT-ECV has been show to correlate with clinical parameters such as GLS and cardiac troponin levels, indicating its utility in reflecting myocardial injury and dysfunction [68].

In CA, CT-ECV has also shown both high diagnostic accuracy and prognostic value. Meta-analyses indicate that CT-ECV values are significantly higher in patients with CA than in controls and those with AS, with pooled CT-ECV values averaging around 50% in amyloidosis compared with approximately 28% in healthy individuals [21]. CT-ECV strongly correlates with MRI-ECV, with correlation coefficients exceeding 0.85 across myocardial segments, and shows significant associations with clinical markers such as high-sensitivity cardiac troponin T and left ventricular ejection function [68,69]. Furthermore, it can differentiate between lone AS and AS complicated by transthyretin amyloidosis, with distinct cutoff values aiding in diagnosis [70]. CT-ECV has also been shown to predict mortality in patients with CA, with higher ECV values indicating worse prognosis [71].

In AS, CT-ECV measured during routine TAVR planning has shown prognostic significance. A meta-analysis including over 1200 patients showed that elevated CT-ECV (>30.7%) was associated with increased cardiovascular events, all-cause mortality, and HF hospitalizations post-TAVR [72]. This finding supports incorporating CT-ECV assessment into preprocedural CT protocols for risk stratification.

Technical advances in CT, such as DECT and PCD-CT, have improved ECV quantification accuracy and reduced radiation dose. Studies comparing various CT acquisition protocols have found that 4-min non-electrocardiogram (ECG)-gated delayed DECT provides ECV measurements comparable to conventional 10-min ECG-gated scans, enhancing clinical workflow [73]. PCD-CT further refines ECV quantification, showing excellent correlation and agreement with MRI-ECV, and enabling simultaneous assessment of coronary artery disease and myocardial structure in CA [36,74].

Notably, CT-ECV has also shown promise beyond cardiac diseases. Elevated CT-ECV has been reported as a predictive biomarker for recurrence and survival in various cancers, including thymomas, pancreatic ductal adenocarcinoma, gastric cancer, and colorectal cancer, reflecting ECM expansion in tumor stroma [75,78]. Although these applications are outside cardiology, they underscore the versatility of CT-ECV as a quantitative imaging biomarker.

Comparative studies consistently demonstrate a strong correlation between CT-ECV and MRI-ECV, with pooled correlation coefficients around 0.9, and mean differences of <1%, confirming CT as a reliable alternative when MRI is either contraindicated or unavailable [79,80]. Segmental analyses reveal that septal myocardial segments yield more consistent ECV measurements than non-septal regions, which may inform regional assessment strategies [79,81]. Furthermore, CT-ECV measurements are feasible and reliable even in patients with AF, where MRI may be challenging [52].

In summary, CT-ECV measurement is a robust, reproducible, and clinically valuable tool for assessing myocardial fibrosis and interstitial expansion in myocarditis, HF, CA, and AS. It provides practical advantages, including wider availability, shorter scan times, and fewer contraindications than MRI. Advances in CT technology, including DECT and PCD-CT, have enhanced CT-ECV's accuracy and clinical applicability. Ongoing research continues to refine CT-ECV protocols and expand its prognostic and diagnostic roles, positioning CT-ECV as an increasingly integral component of cardiovascular imaging.

2.4. Consistency Study of ECV Measurement Between CT and MRI

2.4.1. Correlation Analysis

The correlation between cardiac CT-ECV and MRI-ECV quantification has been extensively investigated across various cardiac pathologies, demonstrating strong concordance and promising clinical applicability of CT-ECV as a reliable alternative to the MRI gold standard. Multiple studies have reported excellent correlations between CT-ECV and MRI-ECV quantification, with Pearson correlation coefficients usually exceeding 0.8, indicating robust linear relationships at both global and segmental myocardial levels. For instance, CT-ECV and MRI-ECV showed high correlations across myocardial segments, including septal (r=0.88) and lateral (r=0.80) walls, in CA with no significant difference in mean global ECV values, underscoring CT's capability to replicate MRI findings with clinical relevance [68]. Similarly, DECT-ECV strongly correlated with MRI-ECV at right ventricular insertion points (r=0.83–0.84) and left ventricular segments (r=0.73–0.79) in pulmonary hypertension, although the correlation was weaker in the right ventricular free wall, reflecting regional variability in measurement accuracy [69].

Meta-analyses consolidating data from multiple studies further affirm the excellent agreement between CT-ECV and MRI-ECV quantification, with pooled correlation coefficients around 0.90 and mean differences of <1%, highlighting CT's precision and reproducibility [82]. Notably, DECT techniques yield higher correlation coefficients than SECT, suggesting that spectral imaging enhances ECV quantification accuracy [82]. PCD-CT, a novel technology, has demonstrated superior correlation and reliability relative to conventional energy-integrating detector CT, particularly in patients with elevated heart rates, with intraclass correlation coefficients reaching up to 0.94, indicating excellent reproducibility [83].

Methodological comparisons within CT modalities reveal that iodine-based dual-energy methods provide more accurate and consistent ECV measurements than standard subtraction methods, with closer agreement to MRI-ECV and lower root mean squared errors, reinforcing the importance of advanced CT post-processing techniques [84]. Additionally, synthetic hematocrit-based ECV calculations, which obviate the need for blood sampling, have shown high correlation with laboratory-derived ECV and MRI reference standards when appropriate image reconstruction algorithms, such as second-generation deep learning reconstruction, are employed to reduce noise and bias [85,86].

Segmental analyses confirm that CT-ECV can discriminate between LGE-positive and LGE-negative myocardial segments with high sensitivity and specificity, with correlation coefficients exceeding 0.9 in ischemic and non-ischemic segments, supporting CT's utility in detecting focal fibrosis [87]. The reproducibility of CT-ECV quantification is further validated in patients with CA, where DECT-ECV measurements show good inter- and intraobserver agreement and test-retest reliability, establishing CT-ECV as a repeatable imaging biomarker [88].

Clinical studies also demonstrate meaningful correlations between CT-ECV and relevant clinical parameters such as high-sensitivity cardiac troponin T, GLS, and left ventricular ejection fraction, paralleling MRI findings and underscoring the prognostic value of CT-ECV [68,89]. CT-ECV correlates strongly with MRI-ECV and functional biomarkers such as peak VO_2 and NT-proBNP, in severe AS and HCM, further validating its clinical applicability [50,90].

However, some limitations and variability exist. For example, CT-ECV measurements performed during arrhythmia in patients with AF show good agreement with MRI-ECV acquired in sinus rhythm, indicating CT's robustness in challenging clinical scenarios [52]. MRI-ECV may not accurately reflect histological amyloid load in CA with myocardial edema, suggesting that multiparametric imaging, including T2 mapping, is necessary for comprehensive tissue characterization [48].

Overall, the body of evidence supports that CT-ECV quantification strongly correlates with MRI-ECV quantification across diverse cardiac diseases and patient populations. Advances in CT technology, including DECT and PCD-CT, combined with optimized reconstruction and synthetic hematocrit methods, have enhanced measurement accuracy and reproducibility. These findings position CT-ECV as a viable, non-invasive imaging biomarker for myocardial fibrosis and ECM expansion, providing a practical alternative to MRI, particularly in patients with contraindications or limited access to MRI. Nonetheless, further large-scale prospective studies are warranted to standardize protocols, validate diagnostic thresholds, and fully establish the prognostic implications of CT-ECV in clinical practice [33–35,82].

2.4.2. Comparison of Clinical Applicability

The clinical applicability of cardiac CT-ECV and MRI-ECV quantification varies based on patient characteristics, clinical settings, and technical considerations, with each modality providing distinct advantages and limitations. Cardiac MRI remains the gold standard for ECV assessment due to its superior soft tissue contrast, established protocols for T1 mapping, and extensive validation in various cardiac pathologies, including cardiomyopathies, myocarditis, and CA. MRI-ECV has demonstrated strong prognostic value, as shown in studies of heart transplant patients, acute myocarditis, and DCM, where elevated ECV correlates with adverse outcomes and disease severity [47,91,92]. MRI also enables comprehensive tissue characterization, including native T1, T2 mapping, and LGE, providing insights into myocardial fibrosis, edema, and inflammation. However, it has contraindications such as implanted devices, claustrophobia, and limited availability, which restrict its use in certain populations.

Cardiac CT has emerged as a promising alternative for ECV quantification, particularly in patients with contraindications to MRI or when rapid assessment is required. Advances in CT technology, including DECT and PCD-CT, have enabled accurate ECV measurement with good correlation to MRI-ECV values across various cardiac conditions such as CA, myocarditis, and pulmonary hypertension [55,68,69]. CT provides practical advantages, including wider availability, shorter examination times, and the ability to simultaneously evaluate coronary anatomy and myocardial tissue characteristics within a single session, which is particularly valuable in ischemic heart disease or pre-procedural planning such as transcatheter aortic valve implantation (TAVI) [33,90]. Furthermore, CT-ECV quantification can be performed with low radiation doses using optimized protocols and reconstruction parameters, enhancing its clinical feasibility [90,93].

CT-ECV quantification has limitations. Radiation exposure, although reduced with modern scanners, remains a consideration, particularly in younger patients or those requiring serial imaging. The accuracy of CT-ECV can be influenced by technical factors such as reconstruction settings, contrast timing, and hematocrit estimation, with synthetic hematocrit models being developed to obviate blood sampling but still requiring further validation [86,94]. CT also has lower soft tissue contrast than MRI, which may limit the detection of subtle myocardial changes or small focal fibrosis. The presence of arrhythmias, such as AF, can affect image quality; however, studies have demonstrated reliable CT-ECV measurements even in patients with AF [52].

The choice between CT and MRI for ECV assessment depends on the clinical question and patient factors in specific clinical scenarios. Both modalities provide comparable ECV quantification for CA, with MRI offering additional tissue characterization and CT serving as a viable alternative when MRI is contraindicated [68,95]. In acute myocarditis, PCD-CT has shown feasibility and accuracy comparable to MRI, with the added benefit of rapid acquisition [55]. For pulmonary hypertension, CT-ECV strongly correlates with MRI-ECV and hemodynamic parameters, suggesting its utility as a non-invasive surrogate marker [69]. MRI-ECV serves as an early biomarker for cardiotoxicity in patients undergoing cancer therapy, while CT may provide an alternative in cases where MRI is not feasible [53].

In summary, cardiac MRI remains the reference standard for myocardial ECV quantification due to its comprehensive tissue characterization and established prognostic value. Cardiac CT, particularly with advanced techniques such as DECT and PCD-CT, provides a practical and accurate alternative for ECV assessment, especially in patients with MRI contraindications or when combined coronary and myocardial evaluation is needed. Moreover, the choice of modality should be individualized, considering clinical context, patient characteristics, and available technology, while ongoing technical improvements and standardization efforts continue to enhance the clinical utility of CT-ECV.

2.5. Future Development Directions

2.5.1. Application of New Technologies

The advent of PCD-CT represents a significant technological leap in cardiac imaging, providing promising improvements in myocardial ECV measurement. PCD-CT utilizes photon-counting detectors that directly convert X-ray photons into electrical signals, enabling superior spatial resolution, enhanced contrast-to-noise ratio, and improved spectral imaging capabilities compared to conventional energy-integrating detector CT systems. Recent studies have demonstrated that PCD-CT can accurately quantify myocardial ECV with strong correlation to cardiac MRI, the current gold standard. For example, in patients with suspected acute myocarditis, PCD-CT-ECV measurements showed no significant difference from MRI-derived values and correlated strongly with LGE mass and segmental MRI-ECV, highlighting its diagnostic accuracy at relatively low radiation doses [55]. Similarly, PCD-CT-ECV quantification in patients with HCM positively correlated with MRI-ECV and showed good sensitivity and specificity in detecting significant myocardial fibrosis, with additional correlations to functional capacity and biomarkers such as peak VO_2 and NT-proBNP levels [50]. These findings underscore the clinical utility of PCD-CT as a non-invasive alternative for myocardial tissue characterization, particularly in patients contraindicated for MRI or requiring combined coronary and myocardial assessment.

Beyond diagnostic accuracy, PCD-CT provides technical advantages that optimize ECV quantification. Therefore, tailoring reconstruction parameters such as quantum iterative reconstruction levels, slice thickness, and virtual monoenergetic imaging energy can substantially improve agreement with MRI-ECV. For instance, using thinner slices (0.4 mm) and lower monoenergetic levels (45 keV) reduced mean bias by 63% and increased concordance by 6% compared with standard settings, thereby enhancing image quality and measurement precision [93]. Moreover, dual-energy PCD-CT acquisitions have been shown to reduce radiation exposure by approximately 40% relative to single-energy acquisitions while maintaining strong correlation and reliability with MRI-ECV measurements [74]. These technological refinements highlight the potential of PCD-CT to become a cornerstone modality for myocardial fibrosis assessment with improved safety profiles.

In addition to PCD-CT, other emerging CT techniques such as DECT and single-source DECT have demonstrated strong correlations with MRI for ECV quantification across various cardiac pathologies, including CA, pulmonary hypertension, and DCM. Dual-energy iodine mapping methods have been shown to yield more accurate ECV quantification than standard subtraction methods, with better agreement to MRI values [84]. Single-source DECT acquisitions added to routine pre-procedural scans, such as before TAVI, can provide ECV measurements with excellent linear relationships to MRI, providing practical clinical integration with minimal additional radiation

[90]. These modalities expand the accessibility of myocardial tissue characterization, particularly in patients with MRI contraindications.

AI and advanced computational methods are also emerging as adjuncts to enhance ECV measurement and interpretation. AI-based assessments integrated with CT imaging can facilitate automated quantification of myocardial mass, epicardial adipose tissue, and plaque characteristics, thereby enriching the prognostic value of ECV measurements [96]. Furthermore, AI and big data analytics hold promise in the early detection and monitoring of cardiotoxicity, potentially refining the clinical applicability of ECV quantification in oncology patients receiving cardiotoxic therapies [97]. These developments suggest a future where multimodal imaging combined with AI-driven analytics could provide comprehensive myocardial tissue characterization and risk stratification.

In summary, emerging technologies, particularly PCD-CT, represent a transformative advancement in myocardial ECV measurement. PCD-CT provides enhanced image quality, reduced radiation dose, and robust correlation with MRI, positioning it as a promising non-invasive tool for myocardial fibrosis assessment. Complemented by DECT techniques and AI integration, these innovations are expanding the clinical utility of ECV quantification, enabling broader application in diverse cardiac diseases and improving diagnostic and prognostic capabilities. Continued research and standardization are needed to fully realize the potential of these innovative technologies in routine clinical practice.

2.5.2. Standardization and Multicenter Studies

Although the clinical application of CT- and MRI-ECV quantification has advanced significantly, the lack of standardized measurement protocols and large-scale multicenter validation remains a critical barrier to widespread adoption. Therefore, establishing unified ECV measurement standards is essential to ensure reproducibility, comparability, and reliability of results across different imaging platforms, institutions, and patient populations. Recent studies have demonstrated that CT-ECV quantification, particularly with innovations such as PCD-CT and DECT, shows strong correlation and good agreement with the MRI gold standard, highlighting the potential for CT as a non-invasive alternative in patients contraindicated for MRI [55,69,74,93]. However, variability in reconstruction parameters, contrast protocols, and post-processing techniques can significantly influence ECV values, as evidenced by the impact of slice thickness, quantum iterative reconstruction levels, and virtual monoenergetic imaging settings on CT-ECV accuracy [93]. This underscores the necessity for consensus on optimal imaging acquisition and analysis parameters.

Multicenter studies are crucial for validating these standardized protocols by encompassing diverse patient cohorts and scanner technologies, thereby enhancing the generalizability of findings. A systematic review and meta-analysis encompassing 73 studies with 15 quantitative datasets confirmed that CT-ECV reliably differentiates pathological myocardial fibrosis from normal myocardium, correlating with adverse clinical outcomes such as HF mortality and advanced cardiomyopathies [34]. The meta-analytic approach also emphasized that advanced CT techniques, including DECT and late iodine enhancement CT, yield diagnostic accuracies comparable to MRI, reinforcing CT-ECV's clinical utility. Nevertheless, the high heterogeneity ($I^2 = 84.6\%$) observed in pooled analyses reflects the variability in methodologies and patient selection, further advocating for standardized protocols and multicenter collaboration.

Moreover, multicenter prospective studies also facilitate the assessment of reproducibility, interobserver variability, and longitudinal prognostic value of ECV measurements. For instance, studies in specific cardiac conditions, such as pulmonary hypertension and spontaneous coronary artery dissection, have demonstrated that CT-ECV correlates with disease severity and myocardial injury, respectively, with strong agreement to MRI findings [69,98]. The development of novel visualization tools, such as atlas maps for myocardial ECV distribution, has also been validated in multicenter settings, enhancing interpretability and clinical decision-making [98]. Pediatric heart transplant recipient studies using multiparametric MRI, including ECV mapping, have highlighted the prognostic significance of elevated ECV, suggesting that similar multicenter investigations with CT could expand clinical applications [99].

Harmonizing hematocrit estimation methods is critical in addition to standardizing imaging protocol, as synthetic hematocrit-based ECV quantification by PCD-CT has shown systematic overestimation and variability compared with MRI, necessitating bias correction models [86]. Therefore, such technical nuances should be addressed in multicenter frameworks to ensure consistency.

In summary, the establishment of unified ECV measurement standards and the execution of multicenter studies are indispensable for translating myocardial ECV quantification from research to routine clinical practice. These efforts will enable robust validation of CT-ECV against MRI, optimize imaging protocols, reduce inter-institutional variability, and ultimately improve diagnostic accuracy and prognostic stratification across diverse cardiac pathologies.

3. Conclusions

The measurement of ECV has emerged as a key parameter in evaluating myocardial tissue characteristics, providing critical insights into diffuse myocardial fibrosis and other pathologies. Both cardiac CT and MRI have proven effective for ECV quantification, each with distinct advantages and limitations. From an expert perspective, understanding the complementary roles of these imaging techniques is essential for optimizing patient care and advancing cardiovascular diagnostics.

MRI remains the gold standard for ECV measurement due to its superior tissue characterization capabilities, high spatial resolution, and lack of ionizing radiation. Its ability to provide comprehensive myocardial assessment, including functional and structural information, makes it indispensable in many clinical scenarios. However, MRI is not without limitations. Contraindications such as implanted metallic devices, claustrophobia, and renal insufficiency restrict MRI's applicability in certain patient populations. Moreover, MRI's longer acquisition times and higher costs can limit accessibility and throughput in busy clinical settings.

In this context, cardiac CT has emerged as a promising alternative for ECV measurement. CT provides rapid image acquisition, widespread availability, and fewer contraindications, making it particularly advantageous for patients who cannot undergo MRI. The recent advancements in CT technology, including dual-energy and spectral imaging, have enhanced its ability to differentiate myocardial tissue components and improve ECV quantification accuracy. The high spatial resolution of CT facilitates detailed anatomical assessment, which can be integrated with ECV data to provide a more comprehensive evaluation of myocardial pathology.

Balancing the research perspectives on CT and MRI for ECV measurement requires acknowledging the strengths and limitations of each modality while striving for methodological standardization. Current literature reveals variability in CT protocols, contrast administration, and post-processing techniques, which can affect measurement reproducibility and comparability across studies. Therefore, future research should prioritize the optimization and harmonization of CT imaging protocols to ensure consistency and reliability. Similarly, ongoing efforts to refine MRI sequences and contrast agents aim to further enhance their diagnostic performance.

Expanding the clinical applications of CT-ECV measurement represents another critical frontier. While MRI has been extensively validated in various cardiomyopathies and infiltrative diseases, the role of CT is still evolving. Prospective studies comparing CT-ECV with histopathological findings and long-term clinical outcomes will be instrumental in establishing its diagnostic and prognostic value. Furthermore, integrating CT-ECV measurement into routine clinical workflows could facilitate earlier detection of myocardial disease, guide therapeutic decisions, and monitor treatment response, especially in patient cohorts unsuitable for MRI.

In conclusion, the development of cardiac CT as a viable alternative to MRI for ECV measurement marks a significant advancement in cardiovascular imaging. By leveraging the unique advantages of CT and addressing current methodological challenges, the medical community can broaden the scope of myocardial tissue characterization. Furthermore, achieving a balanced and evidence-based integration of CT and MRI modalities will ultimately enhance diagnostic accuracy, personalize patient management, and improve clinical outcomes in cardiovascular disease. Continued multidisciplinary collaboration and rigorous research are essential to realize the full potential of ECV measurement in clinical practice.

Abbreviations

The following abbreviations are used in this manuscript:

AF	Atrial Fibrillation
AUC	Area Under the Curve
AS	Aortic Stenosis
AI	Artificial Intelligence
CA	Cardiac Amyloidosis
CT	Computed Tomography
CT-ECV	Computed Tomography-Derived Extracellular Volume
DCM	Dilated Cardiomyopathy
DECT	Dual-Energy Computed Tomography
DECT-ECV	Dual-Energy Computed Tomography-Extracellular Volume
ECM	Extracellular Matrix
ECV	Extracellular Volume
GLS	Global Longitudinal Strain
GPA	Granulomatosis with Polyangiitis
HF	Heart Failure
HCM	Hypertrophic Cardiomyopathy
IMIDs	Immune-Mediated Inflammatory Diseases
LGE	Late Gadolinium Enhancement
MACE	Major Adverse Cardiovascular Events
MOLLI	Modified Look-Locker Inversion Recovery
MRI	Magnetic Resonance Imaging
MRI-ECV	Magnetic Resonance Imaging-Extracellular Volume
NT-proBNP	N-terminal pro–B-type Natriuretic Peptide
PCD-CT	Photon-Counting Detector Computed Tomography
PCD-CT-ECV	Photon-Counting Detector Computed Tomography-derived Extracellular Volume
SSc	Systemic Sclerosis
SECT	Single-Energy Computed Tomography
TAVI	Transcatheter Aortic Valve Implantation
TAVR	Transcatheter Aortic Valve Replacement

References

1. Zhang SJ, Chang D, Jin JY, et al. Myocardial Extracellular Volume Fraction Measured by Cardiac Magnetic Resonance Imaging Negatively Correlates With Cardiomyocyte Breadth in a Healthy Porcine Model. Front Cardiovasc Med. 9:791963. Published 2022 None. doi:10.3389/fcvm.2022.791963 https://pubmed.ncbi.nlm.nih.gov/35369328/
2. Corpataux N, Haider A, Fuentes Artiles R, et al. Effect of age and sex on cardiac magnetic resonance native T1 mapping and synthetic extracellular volume. Int J Cardiol. 442:133818. Published online Aug 27,2025. doi:10.1016/j.ijcard.2025.133818 https://pubmed.ncbi.nlm.nih.gov/40882774/
3. Nickander J, Themudo R, Sigfridsson A, Xue H, Kellman P, Ugander M. Females have higher myocardial perfusion, blood volume and extracellular volume compared to males - an adenosine stress cardiovascular magnetic resonance study. Sci Rep. 2020;10(1):10380. Published 2020 Jun 25. doi:10.1038/s41598-020-67196-y https://pubmed.ncbi.nlm.nih.gov/32587326/
4. Yang B, Qiao Y, Yan D, Meng Q. Targeting Interactions between Fibroblasts and Macrophages to Treat Cardiac Fibrosis. Cells. 2024;13(9). Published 2024 Apr 30. doi:10.3390/cells13090764 https://pubmed.ncbi.nlm.nih.gov/38727300/

5. Blythe HC, Adams ZH, Hope KA, et al. Sympathetic reactivity to physiological stress is associated with expanded cardiac extracellular volume in humans. BMC Med. 2025;23(1):367. Published 2025 Jul 1. doi:10.1186/s12916-025-04197-6 https://pubmed.ncbi.nlm.nih.gov/40597238/
6. Yang J, Wang Z, Wang H, et al. Myocardial Transit Time Mapping by CMR: A Novel Indicator of Microcirculatory Dysfunction in Cardiac Amyloidosis. J Imaging Inform Med. 2024;37(6):3049-3056. doi:10.1007/s10278-024-01179-7 https://pubmed.ncbi.nlm.nih.gov/38940890/
7. Ventura-Antunes L, Nackenoff A, Romero-Fernandez W, et al. Arteriolar degeneration and stiffness in cerebral amyloid angiopathy are linked to Aβ deposition and lysyl oxidase. Alzheimers Dement. 2025;21(6):e70254. doi:10.1002/alz.70254 https://pubmed.ncbi.nlm.nih.gov/40465757/
8. Soni RK, Dimapanat L, Katari MS, Rai AJ. An Optimized Procedure for Proteomic Analysis of Extracellular Vesicles Using In-Stage Tip Digestion and DIA LC-MS/MS: Application to Liquid Biopsy in Cancer. Methods Mol Biol. 2546:401-409. doi:10.1007/978-1-0716-2565-1_35 https://pubmed.ncbi.nlm.nih.gov/36127607/
9. Feraille É, Olivier V. [Role of distal nephron in the control of extracellular volume in physiology and in nephrotic syndrome]. Med Sci (Paris). 2021;37(4):359-365. doi:10.1051/medsci/2021032 https://pubmed.ncbi.nlm.nih.gov/33908853/
10. Buryskova Salajova K, Malik J, Valerianova A. Cardiorenal Syndromes and Their Role in Water and Sodium Homeostasis. Physiol Res. 2024;73(2):173-187. https://pubmed.ncbi.nlm.nih.gov/38710052/
11. Mullins L, Ivy J, Ward M, et al. Abnormal neonatal sodium handling in skin precedes hypertension in the SAME rat. Pflugers Arch. 2021;473(6):897-910. doi:10.1007/s00424-021-02582-7 https://pubmed.ncbi.nlm.nih.gov/34028587/
12. Gong X, Nguyen R, Chen Z, Wen Z, Zhang X, Mak M. Volumetric Compression Shifts Rho GTPase Balance and Induces Mechanobiological Cell State Transition. bioRxiv. . Published 2023 Oct 10. doi:10.1101/2023.10.08.561452 https://pubmed.ncbi.nlm.nih.gov/37873466/
13. Zannetti A, Benga G, Brunetti A, Napolitano F, Avallone L, Pelagalli A. Role of Aquaporins in the Physiological Functions of Mesenchymal Stem Cells. Cells. 2020;9(12). Published 2020 Dec 13. doi:10.3390/cells9122678 https://pubmed.ncbi.nlm.nih.gov/33322145/
14. Mascherbauer K, Kronberger C, Donà C, et al. Comparative Assessment of CMR-Determined Extracellular Volume Metrics in Predicting Adverse Outcomes. J Clin Med. 2025;14(2). Published 2025 Jan 9. doi:10.3390/jcm14020382 https://pubmed.ncbi.nlm.nih.gov/39860388/
15. Fröjdh F, Fridman Y, Bering P, et al. Extracellular Volume and Global Longitudinal Strain Both Associate With Outcomes But Correlate Minimally. JACC Cardiovasc Imaging. 2020;13(11):2343-2354. doi:10.1016/j.jcmg.2020.04.026 https://pubmed.ncbi.nlm.nih.gov/32563637/
16. Li B, Gao Y, Wang W, et al. Epicardial Adipose Tissue and Extracellular Volume Fraction in Patients with Hypertrophic Cardiomyopathy: A Multi-center Prognosis Study. Acad Radiol. 2025;32(8):4435-4444. doi:10.1016/j.acra.2025.04.015 https://pubmed.ncbi.nlm.nih.gov/40268603/
17. Thongsongsang R, Songsangjinda T, Tanapibunpon P, Krittayaphong R. Native T1 mapping and extracellular volume fraction for differentiation of myocardial diseases from normal CMR controls in routine clinical practice. BMC Cardiovasc Disord. 2021;21(1):270. Published 2021 Jun 3. doi:10.1186/s12872-021-02086-3 https://pubmed.ncbi.nlm.nih.gov/34082703/
18. He J, Xu J, Chen L, et al. Clinical features and cardiovascular magnetic resonance characteristics in Danon disease. Clin Radiol. 2020;75(9):712.e1-712.e11. doi:10.1016/j.crad.2020.04.012 https://pubmed.ncbi.nlm.nih.gov/32499120/
19. Takazaki KAG, Quinaglia T, Venancio TD, et al. Pre-clinical left ventricular myocardial remodeling in patients with Friedreich's ataxia: A cardiac MRI study. PLoS One. 2021;16(3):e0246633. Published 2021 None. doi:10.1371/journal.pone.0246633 https://pubmed.ncbi.nlm.nih.gov/33770103/
20. Rettl R, Calabretta R, Duca F, et al. DPD Quantification Correlates With Extracellular Volume and Disease Severity in Wild-Type Transthyretin Cardiac Amyloidosis. JACC Adv. 2024;3(10):101261. Published 2024 Oct. doi:10.1016/j.jacadv.2024.101261 https://pubmed.ncbi.nlm.nih.gov/39309666/
21. Kato S, Misumi Y, Horita N, Yamamoto K, Utsunomiya D. Clinical Utility of Computed Tomography-Derived Myocardial Extracellular Volume Fraction: A Systematic Review and Meta-Analysis. JACC

Cardiovasc Imaging. 2024;17(5):516-528. doi:10.1016/j.jcmg.2023.10.008 https://pubmed.ncbi.nlm.nih.gov/37999657/

22. Son J, Hong YJ. Treatment Response Evaluation of Cardiac Amyloidosis Using Serial T1- and T2-Mapping Cardiovascular Magnetic Resonance Imaging. Taehan Yongsang Uihakhoe Chi. 2021;82(2):429-434. doi:10.3348/jksr.2020.0048 https://pubmed.ncbi.nlm.nih.gov/36238733/
23. Dumitru RB, Bissell LA, Erhayiem B, et al. Predictors of subclinical systemic sclerosis primary heart involvement characterised by microvasculopathy and myocardial fibrosis. Rheumatology (Oxford). 2021;60(6):2934-2945. doi:10.1093/rheumatology/keaa742 https://pubmed.ncbi.nlm.nih.gov/34080001/
24. Zhao Z, Zhao YN, Jin JY, Yang JS, Zhu J, Li T. [Application of cardiac magnetic resonance imaging in subclinical systemic sclerosis primary heart involvement]. Zhonghua Nei Ke Za Zhi. 2024;63(2):176-182. doi:10.3760/cma.j.cn112138-20231101-00277 https://pubmed.ncbi.nlm.nih.gov/38326044/
25. Giollo A, Dumitru RB, Swoboda PP, et al. Cardiac magnetic resonance imaging for the detection of myocardial involvement in granulomatosis with polyangiitis. Int J Cardiovasc Imaging. 2021;37(3):1053-1062. doi:10.1007/s10554-020-02066-2 https://pubmed.ncbi.nlm.nih.gov/33057879/
26. Black N, Bradley J, Soltani F, et al. Determinants of myocardial fibrosis in patients with immune-mediated inflammatory diseases. Adv Rheumatol. 2025;65(1):28. Published 2025 Jun 14. doi:10.1186/s42358-025-00451-w https://pubmed.ncbi.nlm.nih.gov/40517266/
27. Bojer AS, Sørensen MH, Gæde P, Madsen PL. Myocardial Extracellular Volume Expansion in Type 2 Diabetes Is Associated With Ischemic Heart Disease, Autonomic Neuropathy, and Active Smoking. Diabetes Care. 2022;45(12):3032-3039. doi:10.2337/dc22-0942 https://pubmed.ncbi.nlm.nih.gov/36215704/
28. Laohabut I, Songsangjinda T, Kaolawanich Y, Yindeengam A, Krittayaphong R. Myocardial Extracellular Volume Fraction and T1 Mapping by Cardiac Magnetic Resonance Compared Between Patients With and Without Type 2 Diabetes, and the Effect of ECV and T2D on Cardiovascular Outcomes. Front Cardiovasc Med. 8:771363. Published 2021 None. doi:10.3389/fcvm.2021.771363 https://pubmed.ncbi.nlm.nih.gov/34950715/
29. Ray EC. Evolving understanding of cardiovascular protection by SGLT2 inhibitors: focus on renal protection, myocardial effects, uric acid, and magnesium balance. Curr Opin Pharmacol. 54:11-17. doi:10.1016/j.coph.2020.06.001 https://pubmed.ncbi.nlm.nih.gov/32682281/
30. Hong JY, Park KY, Kim JD, Hwang WM, Lim DM. Effects of 6 Months of Dapagliflozin Treatment on Metabolic Profile and Endothelial Cell Dysfunction for Obese Type 2 Diabetes Mellitus Patients without Atherosclerotic Cardiovascular Disease. J Obes Metab Syndr. 2020;29(3):215-221. doi:10.7570/jomes20040 https://pubmed.ncbi.nlm.nih.gov/32990259/
31. Feroze R, Kang P, Dallan LAP, et al. Elevated myocardial extracellular volume fraction is associated with the development of conduction pathway defects following transcatheter aortic valve replacement. Catheter Cardiovasc Interv. 2024;104(5):1119-1128. doi:10.1002/ccd.31136 https://pubmed.ncbi.nlm.nih.gov/38952304/
32. Niu J, Zeng M, Wang Y, et al. Sensitive marker for evaluation of hypertensive heart disease: extracellular volume and myocardial strain. BMC Cardiovasc Disord. 2020;20(1):292. Published 2020 Jun 15. doi:10.1186/s12872-020-01553-7 https://pubmed.ncbi.nlm.nih.gov/32539749/
33. Cundari G, Galea N, Mergen V, Alkadhi H, Eberhard M. Myocardial extracellular volume quantification with computed tomography-current status and future outlook. Insights Imaging. 2023;14(1):156. Published 2023 Sep 25. doi:10.1186/s13244-023-01506-6 https://pubmed.ncbi.nlm.nih.gov/37749293/
34. Martuszewski A, Paluszkiewicz P, Poręba R, Gać P. Clinical Significance of Extracellular Volume of Myocardium (ECV) Assessed by Computed Tomography: A Systematic Review and Meta-Analysis. J Clin Med. 2025;14(6). Published 2025 Mar 18. doi:10.3390/jcm14062066 https://pubmed.ncbi.nlm.nih.gov/40142874/
35. Muthalaly RG, Abrahams T, Lin A, et al. Myocardial extracellular volume measurement using cardiac computed tomography. Int J Cardiovasc Imaging. 2024;40(11):2237-2245. doi:10.1007/s10554-024-03226-4 https://pubmed.ncbi.nlm.nih.gov/39400790/

36. Popp S, Beitzke D, Strassl A, et al. Evaluation of Extracellular Volume and Coronary Artery Disease in Cardiac Amyloidosis Using Photon-Counting CT. Invest Radiol. 2025;60(10):698-707. Published 2025 Oct 1. doi:10.1097/RLI.0000000000001198 https://pubmed.ncbi.nlm.nih.gov/40279664/
37. Bauer WR. [Cardiac MRI today]. Dtsch Med Wochenschr. 2021;146(5):344-350. doi:10.1055/a-1239-5068 https://pubmed.ncbi.nlm.nih.gov/33648004/
38. Busse A, Rajagopal R, Yücel S, et al. Cardiac MRI-Update 2020. Radiologe. 2020;60(Suppl 1):33-40. doi:10.1007/s00117-020-00687-1 https://pubmed.ncbi.nlm.nih.gov/32385547/
39. Russo V, Lovato L, Ligabue G. Cardiac MRI: technical basis. Radiol Med. 2020;125(11):1040-1055. doi:10.1007/s11547-020-01282-z https://pubmed.ncbi.nlm.nih.gov/32939626/
40. Fadl SA, Revels JW, Rezai Gharai L, et al. Cardiac MRI of Hereditary Cardiomyopathy. Radiographics. 2022 May-Jun;42(3):625-643. doi:10.1148/rg.210147 https://pubmed.ncbi.nlm.nih.gov/35275782/
41. Lücke C, Gutberlet M. [Cardiac MRI in nonischemic cardiomyopathies]. Radiologie (Heidelb). 2022;62(11):920-932. doi:10.1007/s00117-022-01068-6 https://pubmed.ncbi.nlm.nih.gov/36129478/
42. Domenech-Ximenos B, Jiménez-Arjona R, Ortiz-Pérez JT, et al. Sudden cardiac death: Risk stratification using cardiac MRI. Radiologia (Engl Ed). 2025 Jul-Aug;67(4):101639. doi:10.1016/j.rxeng.2025.101639 https://pubmed.ncbi.nlm.nih.gov/40675721/
43. Santini F, Gui L, Lorton O, et al. Ultrasound-driven cardiac MRI. Phys Med. 70:161-168. doi:10.1016/j.ejmp.2020.01.008 https://pubmed.ncbi.nlm.nih.gov/32032800/
44. Kato S, Azuma M, Horita N, Utsunomiya D. Monitoring the Efficacy of Tafamidis in ATTR Cardiac Amyloidosis by MRI-ECV: A Systematic Review and Meta-Analysis. Tomography. 2024;10(8):1303-1311. Published 2024 Aug 16. doi:10.3390/tomography10080097 https://pubmed.ncbi.nlm.nih.gov/39195732/
45. Aun JA, Kwong R, Weber B. Cardiac MRI in Rheumatic Disease. Rheum Dis Clin North Am. 2024;50(4):735-756. doi:10.1016/j.rdc.2024.07.010 https://pubmed.ncbi.nlm.nih.gov/39415377/
46. Jia SQ, Lv SY, Jin YH, et al. Cardiac MRI for clinical dilated cardiomyopathy: Improved diagnostic power via combined T1, T2, and ECV. Radiography (Lond). 2024;30(3):926-931. doi:10.1016/j.radi.2024.04.005 https://pubmed.ncbi.nlm.nih.gov/38657385/
47. Chaikriangkrai K, Abbasi MA, Sarnari R, et al. Prognostic Value of Myocardial Extracellular Volume Fraction and T2-mapping in Heart Transplant Patients. JACC Cardiovasc Imaging. 2020;13(7):1521-1530. doi:10.1016/j.jcmg.2020.01.014 https://pubmed.ncbi.nlm.nih.gov/32199848/
48. Kidoh M, Oda S, Takashio S, et al. MRI-Extracellular Volume Fraction Versus Histological Amyloid Load in Cardiac Amyloidosis: The Importance of T2 Mapping. Circ Cardiovasc Imaging. 2025;18(5):e017427. doi:10.1161/CIRCIMAGING.124.017427 https://pubmed.ncbi.nlm.nih.gov/40116000/
49. Yamaguchi S, Oda S, Kidoh M, et al. Cardiac MRI T1 and T2 Mapping as a Quantitative Imaging Biomarker in Transthyretin Amyloid Cardiomyopathy. Acad Radiol. 2024;31(2):514-522. doi:10.1016/j.acra.2023.08.045 https://pubmed.ncbi.nlm.nih.gov/37775448/
50. Gkizas C, Longere B, Bechrouri S, et al. Photon-counting CT myocardial extracellular volume: A non-invasive biomarker for fibrosis in patients with hypertrophic cardiomyopathy. Diagn Interv Imaging. . Published online Sep 12,2025. doi:10.1016/j.diii.2025.09.001 https://pubmed.ncbi.nlm.nih.gov/40945993/
51. Bakermans AJ, Kouwenhoven M, de Vos J, et al. A comparison of myocardial magnetic resonance extracellular volume mapping at 3 T against histology of tissue collagen in severe aortic valve stenosis and obstructive hypertrophic cardiomyopathy. MAGMA. 2023;36(5):701-709. doi:10.1007/s10334-023-01070-6 https://pubmed.ncbi.nlm.nih.gov/36820958/
52. Kagawa Y, Takafuji M, Fujita S, et al. Myocardial extracellular volume fraction estimations using late enhancement CT in patients with atrial fibrillation: a comparative study with cardiac MR. Int J Cardiovasc Imaging. 2025;41(3):419-426. doi:10.1007/s10554-024-03316-3 https://pubmed.ncbi.nlm.nih.gov/39883382/
53. Folco G, Monti CB, Zanardo M, et al. MRI-derived extracellular volume as a biomarker of cancer therapy cardiotoxicity: systematic review and meta-analysis. Eur Radiol. 2024;34(4):2699-2710. doi:10.1007/s00330-023-10260-8 https://pubmed.ncbi.nlm.nih.gov/37823922/
54. Zhang H, Shi C, Yang L, et al. Quantification of Early Diffuse Myocardial Fibrosis Through 7.0 T Cardiac Magnetic Resonance T1 Mapping in a Type 1 Diabetic Mellitus Mouse Model. J Magn Reson Imaging. 2023;57(1):167-177. doi:10.1002/jmri.28207 https://pubmed.ncbi.nlm.nih.gov/35436040/

55. Gkizas C, Longere B, Sliwicka O, et al. Photon-counting CT-derived extracellular volume in acute myocarditis: Comparison with cardiac MRI. Diagn Interv Imaging. 2025 Jul-Aug;106(7-8):255-263. doi:10.1016/j.diii.2025.03.001 https://pubmed.ncbi.nlm.nih.gov/40102107/
56. Ibrahim EH, Rubenstein J, Sosa A, et al. Myocardial Strain for the Differentiation of Myocardial Involvement in the Post-Acute Sequelae of COVID-19-A Multiparametric Cardiac MRI Study. Tomography. 2024;10(3):331-348. Published 2024 Feb 27. doi:10.3390/tomography10030026 https://pubmed.ncbi.nlm.nih.gov/38535768/
57. Clerc OF, Cuddy SAM, Jerosch-Herold M, et al. Myocardial Characteristics, Cardiac Structure, and Cardiac Function in Systemic Light-Chain Amyloidosis. JACC Cardiovasc Imaging. 2024;17(11):1271-1286. doi:10.1016/j.jcmg.2024.05.004 https://pubmed.ncbi.nlm.nih.gov/39001736/
58. Lu G, Cao L, Ye W, et al. Incremental Prognostic Value of Cardiac MRI Feature Tracking and T1 Mapping in Arrhythmogenic Right Ventricular Cardiomyopathy. Radiol Cardiothorac Imaging. 2024;6(5):e230430. doi:10.1148/ryct.230430 https://pubmed.ncbi.nlm.nih.gov/39446042/
59. Toia P, La Grutta L, Sollami G, et al. Technical development in cardiac CT: current standards and future improvements-a narrative review. Cardiovasc Diagn Ther. 2020;10(6):2018-2035. doi:10.21037/cdt-20-527 https://pubmed.ncbi.nlm.nih.gov/33381441/
60. Shih YT, Zhou JH, Hsiao JK. Cardiac computed tomography: Current practice, guidelines, applications, and prospects. Tzu Chi Med J. 2025 Apr-Jun;37(2):145-151. Published 2025 Apr-Jun None. doi:10.4103/tcmj.tcmj_125_24 https://pubmed.ncbi.nlm.nih.gov/40321959/
61. Chidambaram VA, Choong MCM, Goud CD. Dual-energy computed tomography of the abdomen: A reliable trouble-shooter. J Clin Imaging Sci. 13:12. Published 2023 None. doi:10.25259/JCIS_25_2023 https://pubmed.ncbi.nlm.nih.gov/37152441/
62. Wang Y, Peng Y, Wang T, et al. The evolution and current situation in the application of dual-energy computed tomography: a bibliometric study. Quant Imaging Med Surg. 2023;13(10):6801-6813. doi:10.21037/qims-23-467 https://pubmed.ncbi.nlm.nih.gov/37869341/
63. Stański M, Michałowska I, Lemanowicz A, et al. Dual-Energy and Photon-Counting Computed Tomography in Vascular Applications-Technical Background and Post-Processing Techniques. Diagnostics (Basel). 2024;14(12). Published 2024 Jun 11. doi:10.3390/diagnostics14121223 https://pubmed.ncbi.nlm.nih.gov/38928639/
64. Mochizuki J, Suzuki M, Misawa S, Matsumi H, Hata Y. Advances in Cardiac Computed Tomography: Highlighting the Diagnostic Potential of Nonelectrocardiography-Synchronized Imaging. JACC Case Rep. 2025;30(19):104026. doi:10.1016/j.jaccas.2025.104026 https://pubmed.ncbi.nlm.nih.gov/40681265/
65. Zsarnóczay E, Varga-Szemes A, Emrich T, et al. Characterizing the Heart and the Myocardium With Photon-Counting CT. Invest Radiol. 2023;58(7):505-514. doi:10.1097/RLI.0000000000000956 https://pubmed.ncbi.nlm.nih.gov/36822653/
66. Costantini P, Groenhoff L, Ostillio E, et al. Advancements in Cardiac CT Imaging: The Era of Artificial Intelligence. Echocardiography. 2024;41(12):e70042. doi:10.1111/echo.70042 https://pubmed.ncbi.nlm.nih.gov/39584228/
67. Deng J, Wang Y, Qi T, et al. Myocardial extracellular volume fraction with spectral detector computed tomography for risk stratification in non-ischemic heart failure. Radiol Med. 2025;130(7):1092-1104. doi:10.1007/s11547-025-02002-1 https://pubmed.ncbi.nlm.nih.gov/40304953/
68. Hayashi H, Oda S, Kidoh M, et al. Myocardial extracellular volume quantification in cardiac amyloidosis: a comparative study between cardiac computed tomography and magnetic resonance imaging. Eur Radiol. 2024;34(2):1016-1025. doi:10.1007/s00330-023-10129-w https://pubmed.ncbi.nlm.nih.gov/37597032/
69. Hayashi H, Oda S, Emoto T, et al. Myocardial extracellular volume quantification by cardiac CT in pulmonary hypertension: Comparison with cardiac MRI. Eur J Radiol. 153:110386. doi:10.1016/j.ejrad.2022.110386 https://pubmed.ncbi.nlm.nih.gov/35661458/
70. Kidoh M, Oda S, Tabata N, et al. CT-derived extracellular volume fraction in aortic stenosis, cardiac amyloidosis, and dual pathology. Eur Heart J Cardiovasc Imaging. 2025;26(3):509-517. doi:10.1093/ehjci/jeae320 https://pubmed.ncbi.nlm.nih.gov/39657958/

71. Deux JF, Nouri R, Tacher V, et al. Diagnostic Value of Extracellular Volume Quantification and Myocardial Perfusion Analysis at CT in Cardiac Amyloidosis. Radiology. 2021;300(2):326-335. doi:10.1148/radiol.2021204192 https://pubmed.ncbi.nlm.nih.gov/34100681/
72. Faggiano A, Gherbesi E, Carugo S, et al. Prognostic value of myocardial computed tomography-derived extracellular volume in severe aortic stenosis requiring aortic valve replacement: a systematic review and meta-analysis. Eur Heart J Cardiovasc Imaging. 2025;26(3):518-531. doi:10.1093/ehjci/jeae324 https://pubmed.ncbi.nlm.nih.gov/39787608/
73. Kojima T, Yamasaki Y, Nishigake D, et al. Clinical utility of non-gated 4-min delayed dual-energy CT for myocardial extracellular volume quantification. Br J Radiol. 2025;98(1168):600-606. doi:10.1093/bjr/tqaf022 https://pubmed.ncbi.nlm.nih.gov/39918967/
74. Aquino GJ, O'Doherty J, Schoepf UJ, et al. Myocardial Characterization with Extracellular Volume Mapping with a First-Generation Photon-counting Detector CT with MRI Reference. Radiology. 2023;307(2):e222030. doi:10.1148/radiol.222030 https://pubmed.ncbi.nlm.nih.gov/36719292/
75. Takumi K, Hakamada H, Nagano H, et al. Postoperative prognostic assessment using ECV fraction derived from equilibrium contrast-enhanced CT in thymomas. Eur J Radiol. 184:111978. doi:10.1016/j.ejrad.2025.111978 https://pubmed.ncbi.nlm.nih.gov/39923595/
76. Ming S, Zhang W, Wang M, et al. Contrast-enhanced CT-Derived extracellular volume fraction predicts survival in postoperative pancreatic cancer patients. Eur J Radiol. 191:112273. doi:10.1016/j.ejrad.2025.112273 https://pubmed.ncbi.nlm.nih.gov/40618544/
77. Yusuke N, Daisuke T, Nobuhiro F, et al. CT-derived extracellular volume fraction as a predictive marker for postoperative recurrence in pStage II-III gastric cancer. Eur Radiol. . Published online Jun 18,2025. doi:10.1007/s00330-025-11765-0 https://pubmed.ncbi.nlm.nih.gov/40531317/
78. Zhou H, Feng Y, Yang S, Li W, Cai Y. Association of CT-derived extracellular volume fraction combined with serological markers with histological grading of colorectal cancer. Medicine (Baltimore). 2025;104(33):e43502. doi:10.1097/MD.0000000000043502 https://pubmed.ncbi.nlm.nih.gov/40826787/
79. Zhang H, Guo H, Liu G, et al. CT for the evaluation of myocardial extracellular volume with MRI as reference: a systematic review and meta-analysis. Eur Radiol. 2023;33(12):8464-8476. doi:10.1007/s00330-023-09872-x https://pubmed.ncbi.nlm.nih.gov/37378712/
80. Kim NY, Im DJ, Youn JC, et al. Synthetic Extracellular Volume Fraction Derived Using Virtual Unenhanced Attenuation of Blood on Contrast-Enhanced Cardiac Dual-Energy CT in Nonischemic Cardiomyopathy. AJR Am J Roentgenol. 2022;218(3):454-461. doi:10.2214/AJR.21.26654 https://pubmed.ncbi.nlm.nih.gov/34643105/
81. Ohta Y, Kishimoto J, Kitao S, et al. Investigation of myocardial extracellular volume fraction in heart failure patients using iodine map with rapid-kV switching dual-energy CT: Segmental comparison with MRI T1 mapping. J Cardiovasc Comput Tomogr. 2020 Jul - Aug;14(4):349-355. doi:10.1016/j.jcct.2019.12.032 https://pubmed.ncbi.nlm.nih.gov/31892473/
82. Han D, Lin A, Kuronuma K, et al. Cardiac Computed Tomography for Quantification of Myocardial Extracellular Volume Fraction: A Systematic Review and Meta-Analysis. JACC Cardiovasc Imaging. 2023;16(10):1306-1317. doi:10.1016/j.jcmg.2023.03.021 https://pubmed.ncbi.nlm.nih.gov/37269267/
83. Bao S, Zhou M, Wang M, Xu Z, Yan F, Yang W. Dual-energy based myocardial extracellular volume quantification with photon-counting detector and energy-integrating detector dual-source computed tomography: comparison with cardiac magnetic resonance. Eur Radiol. . Published online Sep 3,2025. doi:10.1007/s00330-025-11942-1 https://pubmed.ncbi.nlm.nih.gov/40903622/
84. Emoto T, Oda S, Kidoh M, et al. Myocardial Extracellular Volume Quantification Using Cardiac Computed Tomography: A Comparison of the Dual-energy Iodine Method and the Standard Subtraction Method. Acad Radiol. 2021;28(5):e119-e126. doi:10.1016/j.acra.2020.03.019 https://pubmed.ncbi.nlm.nih.gov/32402786/
85. Morioka T, Kato S, Onoma A, et al. Improvement of Quantification of Myocardial Synthetic ECV with Second-Generation Deep Learning Reconstruction. J Cardiovasc Dev Dis. 2024;11(10). Published 2024 Oct 2. doi:10.3390/jcdd11100304 https://pubmed.ncbi.nlm.nih.gov/39452275/

86. Hagar MT, Moore WG, Vecsey-Nagy M, et al. Synthetic hematocrit-based extracellular volume quantification from photon-counting CT: Validation against MRI and systematic bias correction. Eur J Radiol. 191:112321. doi:10.1016/j.ejrad.2025.112321 https://pubmed.ncbi.nlm.nih.gov/40684713/
87. Liu P, Lin L, Xu C, et al. Quantitative analysis of late iodine enhancement using dual-layer spectral detector computed tomography: comparison with magnetic resonance imaging. Quant Imaging Med Surg. 2022;12(1):310-320. doi:10.21037/qims-21-344 https://pubmed.ncbi.nlm.nih.gov/34993080/
88. Kadoya Y, Omaygenc MO, Chow B, Small GR. Reproducibility of myocardial extracellular volume quantification using dual-energy computed tomography in patients with cardiac amyloidosis. J Cardiovasc Comput Tomogr. 2025 Jan-Feb;19(1):74-80. doi:10.1016/j.jcct.2024.09.011 https://pubmed.ncbi.nlm.nih.gov/39368897/
89. Lisi C, Mergen V, Moser LJ, et al. Relationship Between Myocardial Strain and Extracellular Volume: Exploratory Study in Patients with Severe Aortic Stenosis Undergoing Photon-Counting Detector CT. Diagnostics (Basel). 2025;15(2). Published 2025 Jan 19. doi:10.3390/diagnostics15020224 https://pubmed.ncbi.nlm.nih.gov/39857108/
90. Dubourg B, Dacher JN, Durand E, et al. Single-source dual energy CT to assess myocardial extracellular volume fraction in aortic stenosis before transcatheter aortic valve implantation (TAVI). Diagn Interv Imaging. 2021;102(9):561-570. doi:10.1016/j.diii.2021.03.003 https://pubmed.ncbi.nlm.nih.gov/33903056/
91. Wang Y, Duan X, Zhu L, et al. Prognostic Value of Myocardial Parametric Mapping in Patients with Acute Myocarditis: A Retrospective Study. Radiol Cardiothorac Imaging. 2025;7(1):e240125. doi:10.1148/ryct.240125 https://pubmed.ncbi.nlm.nih.gov/39912725/
92. Zhou D, Zhang H, Yang W, et al. Risk Stratification of Sudden Cardiac Death in Nonischemic Dilated Cardiomyopathy: Arrhythmogenic Substrate Assessment in Cardiac MRI. Radiology. 2025;316(3):e243427. doi:10.1148/radiol.243427 https://pubmed.ncbi.nlm.nih.gov/40923889/
93. Gnasso C, Pinos D, Schoepf UJ, et al. Impact of reconstruction parameters on the accuracy of myocardial extracellular volume quantification on a first-generation, photon-counting detector CT. Eur Radiol Exp. 2024;8(1):70. Published 2024 Jun 19. doi:10.1186/s41747-024-00469-7 https://pubmed.ncbi.nlm.nih.gov/38890175/
94. Özcan Ç, Yiğit H, Çetin MS, Özcan İ, Tokur O. Optimizing synthetic hematocrit for cardiac MRI: a multivariable model calibrated with standardized venous sampling. Int J Cardiovasc Imaging. . Published online Aug 22,2025. doi:10.1007/s10554-025-03504-9 https://pubmed.ncbi.nlm.nih.gov/40844727/
95. Tavoosi A, Brito JBO, El Mais H, et al. Dual versus single energy cardiac CT to measure extra cellular volume in cardiac amyloidosis: Correlations with cardiac MRI. Int J Cardiol Heart Vasc. 44:101166. Published 2023 Feb. doi:10.1016/j.ijcha.2022.101166 https://pubmed.ncbi.nlm.nih.gov/36620203/
96. Rubio PM, Garcia-Garcia HM, Sanchez AA, et al. Key advances in cardiac computed tomography: A review of the most relevant studies published in 2024 on coronary and structural heart disease. J Cardiovasc Comput Tomogr. 2025 May-Jun;19(3):291-298. doi:10.1016/j.jcct.2025.04.008 https://pubmed.ncbi.nlm.nih.gov/40300917/
97. Kwan JM, Oikonomou EK, Henry ML, Sinusas AJ. Multimodality Advanced Cardiovascular and Molecular Imaging for Early Detection and Monitoring of Cancer Therapy-Associated Cardiotoxicity and the Role of Artificial Intelligence and Big Data. Front Cardiovasc Med. 9:829553. Published 2022 None. doi:10.3389/fcvm.2022.829553 https://pubmed.ncbi.nlm.nih.gov/35369354/

98. Klambauer K, Klotz E, Moser LJ, et al. Myocardial Late Enhancement With Photon-Counting Detector CT in Spontaneous Coronary Artery Dissection: Prospective Comparison With Cardiac MRI. Invest Radiol. . Published online Apr 25,2025. doi:10.1097/RLI.0000000000001203 https://pubmed.ncbi.nlm.nih.gov/40273434/

99. Lawson AA, Watanabe K, Griffin L, et al. Multiparametric cardiovascular magnetic resonance is associated with outcomes in pediatric heart transplant recipients. J Cardiovasc Magn Reson. 2025;27(1):101138. doi:10.1016/j.jocmr.2024.101138 https://pubmed.ncbi.nlm.nih.gov/39725234/