Emerging role of cardiac computed tomography in heart failure

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Abstract

Despite medical advancements, the prognosis of patients with heart failure remains poor. While echocardiography and cardiac magnetic resonance imaging remain at the forefront of diagnosing and monitoring patients with heart failure, cardiac computed tomography (CT) has largely been considered to have a limited role. With the advancements in scanner design, technology, and computer processing power, cardiac CT is now emerging as a valuable adjunct to clinicians managing patients with heart failure. In the current manuscript, we review the current applications of cardiac CT to patients with heart failure and also the emerging areas of research where its clinical utility is likely to extend into the realm of treatment, procedural planning, and advanced heart failure therapy implementation.

Introduction

Heart failure is a complex clinical syndrome involving structural or functional abnormalities of the heart leading to diminished cardiac output. Despite significant improvements in cardiovascular therapeutic interventions in recent years, there has continued to be a significant increase in the burden of heart failure with its considerable associated morbidity and mortality.[1,2]

Cardiac imaging plays a fundamental role in establishing a diagnosis and guiding treatment decisions for patients with heart failure. The current European Society of Cardiology (ESC) guidelines indicate echocardiography as the front-line investigation to establish ventricular function abnormalities in patients with suspected heart failure.[3] Cardiac magnetic resonance (CMR) imaging is reserved for patients with suboptimal echocardiographic windows, complex congenital heart disease or to characterize the myocardium. A lesser role exists for cardiac computed tomographic angiography (CTA) where it receives an isolated Class IIb indication for the exclusion of obstructive coronary artery disease (CAD) in low-intermediate risk patients.

There have been a number of advances in cardiac computed tomography (CT) technology over the last decade. These include scanners with wider detectors to enable single heart beat scanning (320 slices), increased temporal resolution by faster gantry rotation times with single X-ray tube scanners (<500 to 250 msec), and the development of dual source CT (temporal resolution down to 66 msec). Spatial resolution has also been improved with the ability to now image structures as small as 0.3 mm. With the advancements in computer processing power, reconstruction algorithms have also evolved from filtered back projection techniques to iterative reconstruction and now model-based iterative reconstruction techniques that have enabled improvements in image quality and a resultant reduction in ionizing radiation dose. Given these advancements, it is perceivable that future iterations of international heart failure guidelines are likely to feature an expanded role for cardiac CTA. The aim of the current manuscript is to review the current and emerging applications of cardiac CTA, with specific reference to patients with heart failure.

Evaluation of coronary disease

Coronary artery disease is recognized as being the principal aetiology in approximately 50% of cases of heart failure.[4] Current ESC guidelines for the diagnosis and treatment of acute and chronic heart failure recommend assessment of possible CAD with invasive coronary angiography (ICA) for patients with heart failure who suffer from angina symptoms refractory to medical therapy and those with a history of symptomatic ventricular arrhythmia or aborted cardiac arrest (Class Ic). ICA is also recommended for patients with heart failure who have an intermediate to high pretest probability of CAD and the presence of ischaemia on non-invasive stress test (Class IIc). Coronary CTA is indicated for the exclusion of obstructive CAD in low-intermediate risk patients. Furthermore, due to the lack of well-defined heart failure populations among existing studies, current recommendations for revascularization in heart failure patients are based on expert consensus opinion and are restricted to the treatment of patients with angina refractory to anti-anginal medications (Class Ia).[3,5]

With its excellent negative predictive value and high specificity for the detection of obstructive CAD[6] even in heart failure populations,[7] there is good reason to suggest that cardiac CTA can be ideally suited as a first line investigation for the evaluation of CAD in this important patient cohort. Its additional advantage is its ability to simultaneously provide information on cardiac chamber size, cardiac anatomy, and extracardiac findings that may be of relevance in patients who have developed heart failure secondary to complex coronary anomalies (*Figure 1*) or multisystem disease processes such as sarcoidosis, rheumatoid arthritis, and chronic lung disease.

Despite these potential advantages, it is accompanied by a modest positive predictive accuracy, a decline in performance with significant coronary calcification, and a disconnect between anatomical and functionally significant disease.[8] To overcome these limitations, there has been interest in utilizing the capabilities of coronary CTA to provide a simultaneous assessment of the functional significance of coronary disease to enhance its performance across the spectrum of CAD. The two main techniques in this regard are CT myocardial perfusion imaging and fractional flow reserve by coronary CTA (FFR$_{CT}$).

CT myocardial perfusion

In the CORE320 study, Rochite *et al.* prospectively evaluated the diagnostic performance of myocardial CT perfusion for the detection of obstructive CAD ($\geq$50% stenosis) against invasive catheter angiography with a corresponding perfusion defect with single photon emission tomography/myocardial perfusion scanning (SPECT/MPS). In this study of 381 patients from 16 centres, the authors were able to demonstrate a sensitivity of 80% and a specificity of 74% for obstructive CAD when compared with the reference standard of ICA plus SPECT/MPS.[9] A subsequent meta-analysis by Tashakkor *et al.* similarly showed a high diagnostic performance for myocardial CT perfusion when compared with stress perfusion CMR giving a per vessel sensitivity, specificity, positive predictive value, and negative predictive value of 94%, 85%, 88%, and 93%, respectively. Importantly, studies incorporated into this meta-analysis included patients with left ventricular ejection fraction (LVEF) $\geq$ 20%, but no specific subset analysis in patients with LVEF <50% was performed.[10] In a meta-analysis of 18 studies, Gonzalez *et al.* showed that the use of CT perfusion with conventional coronary CTA increased the specificity of coronary CTA from 43% to 77%

Figure 1 Volume rendered coronary CTA image a female patient who presented with cardiogenic shock. Panel (A) shows a large dilated tortuous right coronary artery. Panel (B) shows the RCA draining into the base of the LV (white arrow) (right coronary artery to LV fistula). Ao denotes aorta, RCA, right coronary artery, and RV, right ventricle.
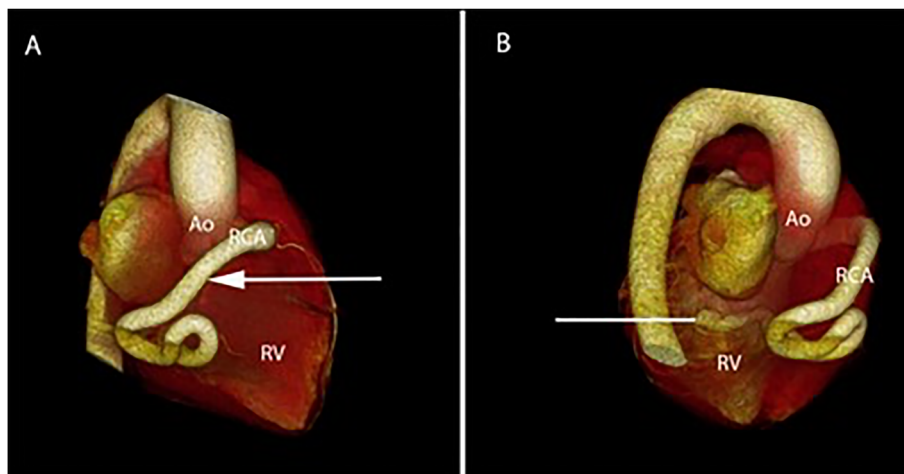
and the positive predictive value from 57% to 83%. However, it also showed an increased pooled radiation dose of 9.6 mSv in studies combining CT perfusion with coronary CTA vs. 3.5 mSv for coronary CTA alone. There was also a higher volume of iodinated contrast used in the protocols combining CT perfusion and coronary CTA.[11]

Fractional flow reserve by coronary computed tomography

Lesion specific ischaemia by fractional flow reserve using coronary CTA can now be acquired using standard coronary CTA acquisitions without the need for extra medication or radiation exposure. This technique has been shown not only to have a high diagnostic accuracy against invasive FFR[12] but also an ability to reduce the need for unnecessary ICA.[13] Although there is no contemporary data validating its use in patients specifically with heart failure, existing studies did not specifically exclude these patients. As the clinical utility of FFR$_{CT}$ increases, its use in patients with heart failure is likely to become more prevalent as clinicians capitalize upon the virtues of having a single anatomical and functional test for CAD.

Ventricular structure and function

Heart failure with reduced ejection fraction

Impaired contractility of the left and right ventricles (LV/RV) late after myocardial infarction is an important predictor of mortality.[14,15] Although echocardiography remains the front-line test to evaluate ventricular function, CMR imaging is now being used increasingly owing to its high diagnostic accuracy and ability to characterize myocardium by late gadolinium enhancement.[16] Cardiac CT is not considered a technique of choice for the evaluation of cardiac function but does retain the capability to measure LV and RV volumes and function for specific indications.[8] This is largely when alternative tests have not been able to provide the required diagnostic information owing to suboptimal echocardiographic

windows or issues relating to claustrophobia or metallic implants with CMR imaging.

In such instances, retrospective multiphase electrocardiogram (ECG)-gated cardiac CT may be considered an accurate and reproducible alternative to CMR with studies showing positive correlation between both for the evaluation of biventricular volumes and function (Table 1).

Regional ventricular function

Multiphase cardiac CT may also be used for the detection of regional wall motion abnormalities (RWMAs) that may indicate rest ischaemia, infarction, or non-ischaemic cardiomyopathies (e.g. cardiac sarcoidosis and prior myocarditis). In a study by Lessick et al. involving 39 patients, cardiac CTA compared favourably against echocardiography. Whereas there was a low sensitivity (52%) in the right coronary artery territory, the left anterior descending artery and left circumflex artery sensitivities fared better with sensitivities of at 78% and 85%, respectively.[17] Using a 17-segment model, Henneman et al. were also able to show an excellent agreement (96%) for the assessment of RWMAs between cardiac CTA and echocardiography.[18]

While it is unlikely that cardiac CTA will replace transthoracic echocardiography or CMR in the evaluation of RWMAs, its cine-loop format may be useful when echocardiography/CMR are not feasible or when cardiac CTA is being carried out for the simultaneous evaluation of CAD and LV function (Figure 2).

Heart failure with preserved ejection fraction

Among patients with clinical heart failure, at least half have heart failure with preserved ejection fraction. Cardiac CTA may be used to derive surrogate markers of diastolic dysfunction by evaluating the change in mitral valve area, mitral septal tissue motion, changes in LV volume, and left atrial total emptying fraction.[19,20] However, further work is required to determine the clinical utility of these newer indices.

Table 1 Relationship between cardiac CTA and CMR-derived evaluation of left and right ventricular ejection fraction and end diastolic volumes

Year	Study	N	Study type	(r) LVEF	(r) RVEF	P-value	(r) LV end-diastolic volume	(r) RV end-diastolic volume	P-value
2008	Plumhans et al.[52]	38	Prospective	—	0.97	P = 0.91	—	0.99	P = 0.91
2010	Guo et al.[53]	56	Prospective	—	0.88	P ≤ 0.01	—	0.75	P ≤ 0.01
2012	Maffei et al.[54]	79	Prospective	0.73	0.74	P ≥ 0.05	0.59	0.58	P ≥ 0.05
2013	Wai et al.[55]	40	Retrospective	0.94	—	—	0.96	—	P ≤ 0.001
2014	Sharma et al.[56]	831	Meta-analysis (27 studies)	0.93	—	P ≤ 0.001	0.93	—	P ≤ 0.001

CMR, cardiac magnetic resonance; CTA, computed tomographic angiography; LV, left ventricle; LVEF, left ventricular ejection fraction; RV, right ventricle; RVEF, right ventricle ejection fraction.

Figure 2 Multiphase cardiac CT showing automated segmentation of the left ventricle (LV) in the short axis view (A), the 4-chamber view (B), and the 2-chamber view (C). Panel (D) shows LV percentage wall thickening, wall thickness, iodine intensity, and segmental ejection fraction. The asterisk shows wall thinning, reduced iodine intensity, and reduced segmental ejection fraction indicating myocardial infarction.
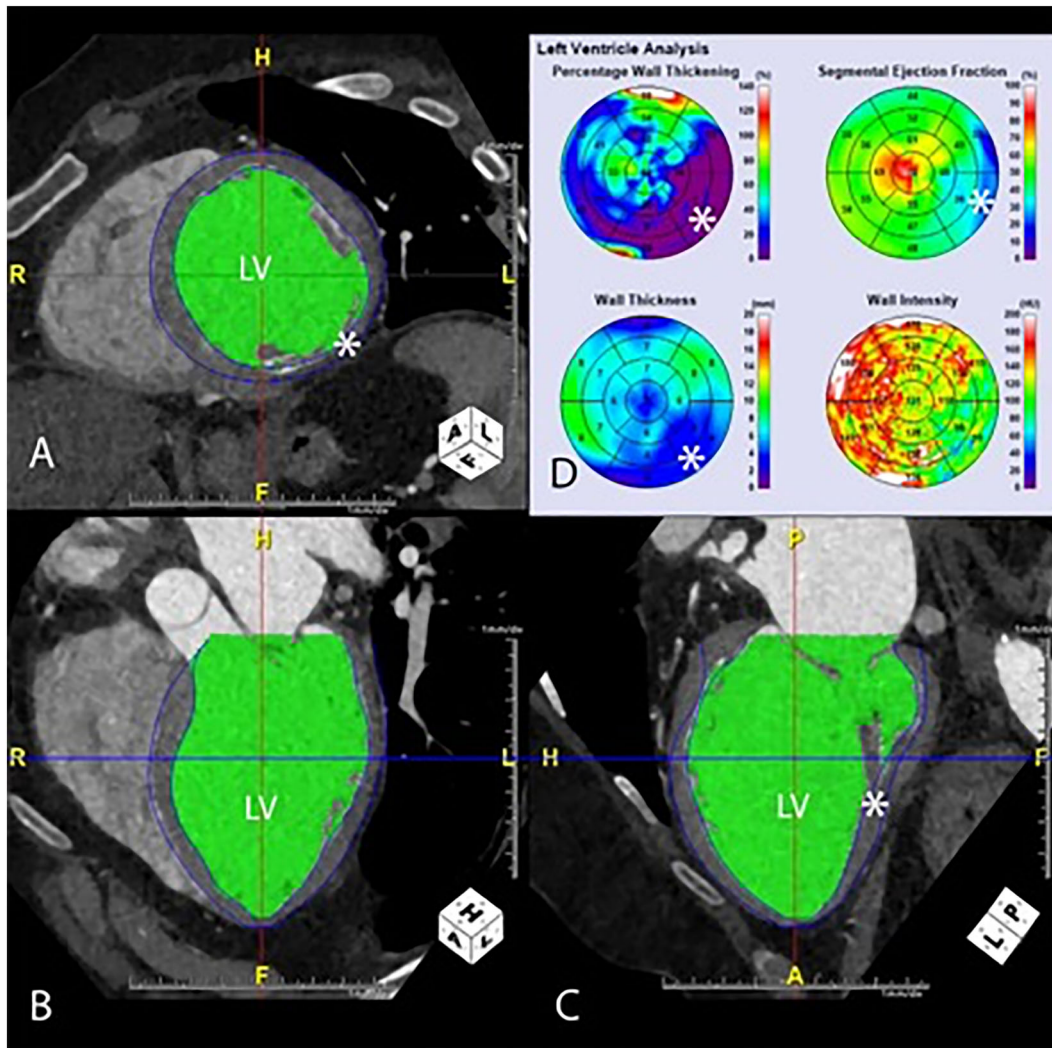
Cardiomyopathies

Given that up to 50% of patients with heart failure have CAD as a confirmed aetiology, an ideal imaging modality would be one that has the ability to detect both ischaemic and non-ischaemic cardiomyopathies. In hypertrophic cardiomyopathy, the findings of myocardial delayed enhancement and LV wall thickness on cardiac CTA show good correlation with that of CMR imaging.[21] Additionally, coronary CTA may be used to guide alcohol septal ablation procedures and plan for surgical myomectomy in patients with significant LV outflow tract obstruction.[22] It may also identify areas of LV non-compaction characterized by pronounced trabeculations, focal thinning, and RWMAs (*Figure 3*).[23] Although not included in the diagnostic Task Force Criteria, CTA may also

reliably identify features consistent with arrhythmogenic right ventricular dysplasia, including RV dilatation with reduced function, the presence of fat in the RV free wall and interventricular septum.[24] In this patient cohort, CT may also be of value for the surveillance of patients who have implantable cardioverter-defibrillator (ICD) device implants or who are being considered for ventricular tachycardia (VT) ablation.[25]

Myocardial tissue characterization

Late gadolinium enhancement on CMR imaging is widely considered to be the clinical gold standard for determining infarct size and viability assessment. This may also be achieved with cardiac CTA, where iodine contrast accumulates in the

Figure 3 Cardiac computed tomography—LV 2-chamber view showing non-compacted (NC) myocardium with associated wall thinning (*) in a patient with left ventricular non-compaction cardiomyopathy. LA, left atrium; LV, left ventricle.
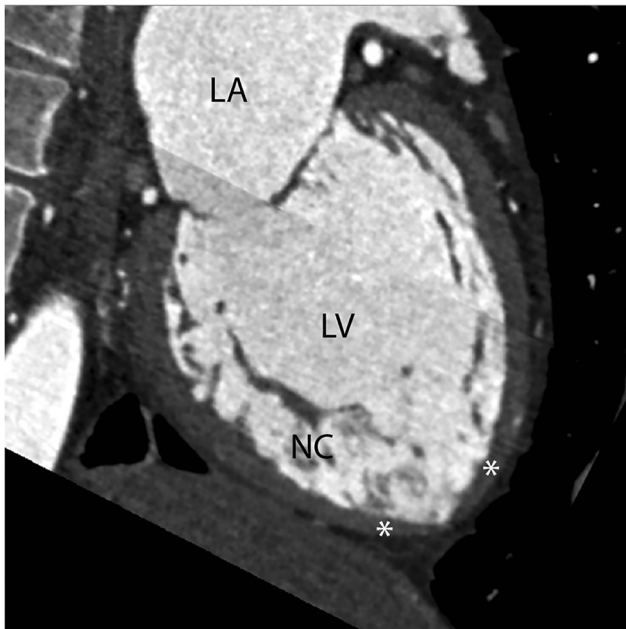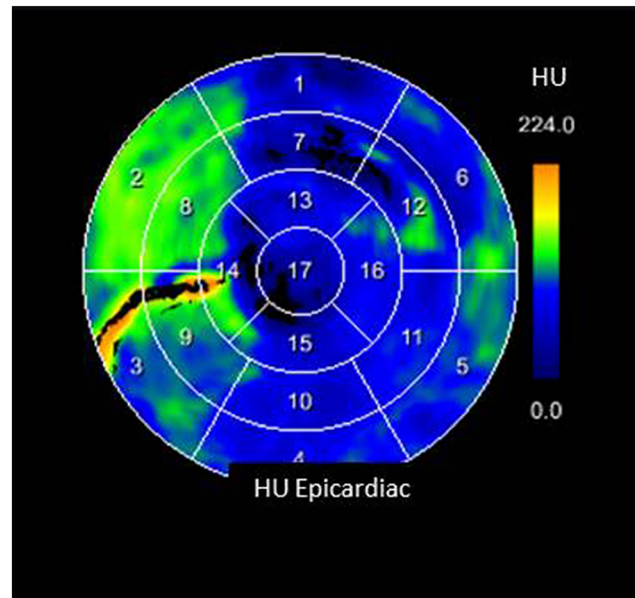

Figure 4 17-Segment left ventricle polar plot of the left ventricle for myocardial scar mapping. Image acquired with dynamic dual source cardiac computed tomography 4 min following contrast administration. Increased Hounsfield unit intensity at the basal–mid anteroseptal and inferoseptal segments is indicative of scar.

increased extracellular space on a delayed scan (5–15 min after ≥120 mL injection of contrast).[26] This technique can accurately quantify infarct size compared with CMR imaging.[27] Furthermore, Sato et al. have also demonstrated the prognostic value of this technique in patients following reperfusion, with larger areas of delayed enhancement being associated with increased cardiac events during follow-up.[28] Despite this early promise, the evaluation of scarred myocardium using cardiac CT remains challenging with there being no standardized accepted imaging protocols in the literature to guide clinicians. It is hoped that with spectral and dual energy cardiac CTA, scar evaluation will become more robust leading to more widespread use when required (Figure 4). It is possible that as scanner technology improves and ionizing radiation doses fall even further, myocardial tissue characterization will be used where this information cannot be obtained by alternative imaging.[8]

For the detection of diffuse myocardial fibrosis in various cardiomyopathies, CMR and T1 mapping enables the quantification of abnormal myocardium and increased extracellular volume. There is now emerging evidence suggesting dual energy and spectral CT may also be used to measure the iodine concentration in the myocardium using a delayed phase scan and thus derive the extracellular volume. Provisional studies demonstrate good agreement with CMR in patients with hypertrophic and dilated cardiomyopathies along with cardiac amyloidosis and sarcoidosis.[29]

Use of cardiac computed tomographic angiography in heart failure treatment

Cardiac resynchronization therapy

Patients with heart failure and bundle branch block exhibit intraventricular dyssynchrony, which is manifested by a delay in mechanical contraction of segments of the LV wall, with consequential dyssynchronous and inefficient global contraction of the LV. The segment with most delayed contraction, called the area of latest mechanical activation, has been identified as an important target for LV lead placement. In cardiac resynchronization therapy (CRT), the area of latest mechanical activation can be targeted by advancing the LV lead into the coronary sinus, eventually positioning it in an adjacent tributary. This necessitates a careful assessment of the cardiac venous anatomy, usually by a coronary venogram. However, an important issue is the variability of the coronary venous anatomy. This coupled with the potential of missing the area of latest mechanical activation may result in non-response to CRT with an associated increased incidence of mortality and heart failure-related hospitalizations.[30]

In this setting, cardiac CT is emerging as a technique that can serve the dual purpose of delineating cardiac venous anatomy as well as identifying optimal sites for LV lead placement that maximizes the haemodynamic response from CRT. Studies have demonstrated the feasibility of retrospective

ECG-gated cardiac CT for the non-invasive assessment of cardiac venous anatomy[31] and have also shown the feasibility of pre-procedural knowledge of cardiac venous anatomy with cardiac CT in guiding LV lead placement.[32] It can thus identify patients with venous anatomy that is unsuitable for LV lead placement (tortuous vessels and absence of suitable target branches) and provide guidance for surgical epicardial or endocardial left ventricular lead placement without the need for invasive contrast venography (*Figure 5*). Furthermore, Behar *et al.* recently evaluated the use of endocardial deformation during the cardiac cycle on cardiac CTA to determine the sites of latest activation. The authors demonstrated that the optimum venous target identified with this method achieved a similar mean acute haemodynamic response compared with the venous target with the best response when measured directly by LV pressure wires.[33]

Techniques to determine the sites of latest activation require ECG-gated multiphase cardiac CTA acquisitions with an associated ionizing radiation expense. Despite this, for patients with difficult echocardiographic windows and existing pacemaker systems, cardiac CT may be useful when coronary anatomy, venous anatomy, accurate LV function, and determination of sites of latest activation are required (*Figure 6*). It is also gaining popularity for imaging lead complications following device implantation and in particular where myocardial lead perforations are suspected.[34]

Electrophysiology

The presence of atrial fibrillation (AF) in heart failure patients has been shown to be an independent predictor of mortality.[35] One treatment option for these patients, when drug anti-arrhythmic therapy fails, is pulmonary vein isolation. In the catheter ablation for AF with heart failure study, Marrouche *et al.* recruited 398 patients with symptomatic paroxysmal or persistent AF in whom anti-arrhythmic therapy had failed or was declined by the patient. All patients also had LVEF ≤35% along with New York Heart Association class II–IV symptoms and were randomized to undergo either catheter ablation or medical therapy (rate or rhythm control) along with standard therapy for heart failure. After 37.8 months median follow-up, the authors found a significantly lower rate of the composite end point of all-cause mortality or hospitalization for worsening heart failure in the catheter ablation arm compared with medical therapy (28.5% vs. 44.6%; $P = 0.007$).[36] To facilitate procedures such as pulmonary vein isolation, cardiac CTA data sets may be merged with intracardiac echocardiography and electroanatomical mapping to improve procedural outcomes.[37] Cardiac CTA has also been used to calculate left atrial wall thickness, which may help to reduce procedural complications (chamber perforation and tamponade) and facilitate success by enabling more effective transmural lesion formation (*Figure 7*).[38] As well as

Figure 5 Panel (A): overlay of the coronary veins onto the 16-segment LV model derived from cardiac CT. Panel (B): coronary venous distribution to the segments with the latest mechanical activation. Panels (C) and (D): CT-fluoro fusion to guide placement of the LV lead at the time of CRT implantation. CRT, cardiac resynchronization therapy; CT, computed tomography; LV, left ventricle.
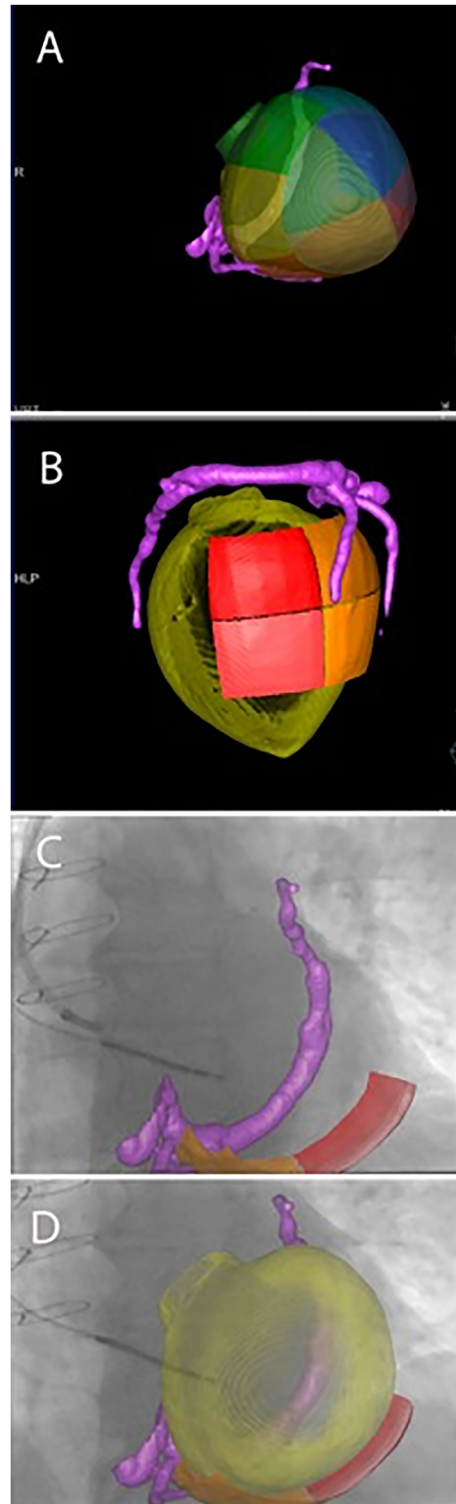
Figure 6 Panel (A): multiphase cardiac computed tomography to evaluate sites of delayed myocardial contraction. Panel (B): volume-based regions of delayed myocardial contractility. Panel (C): global visualization of regional endocardial deformation. LA, left atrium; LV, left ventricle.
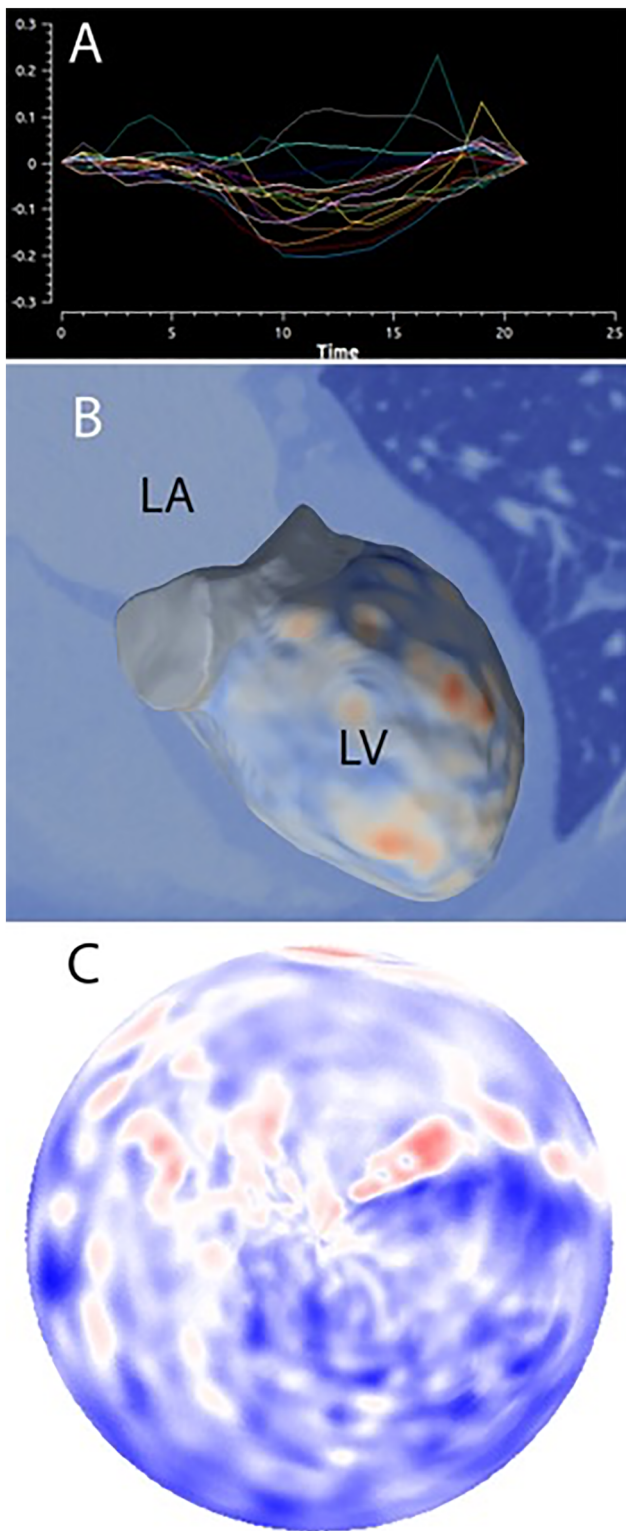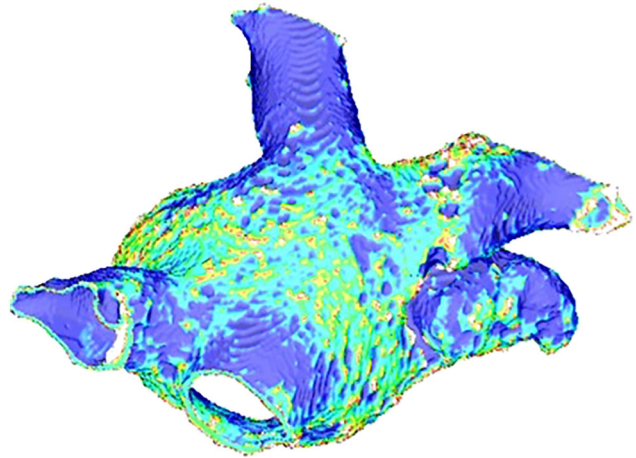

Figure 7 Automated derivation of relative left atrial wall thickness from cardiac computed tomography to help guide pulmonary vein isolation procedures for atrial fibrillation.

guiding therapy, cardiac CTA may also be used to detect left atrial appendage thrombus using a first pass contrast scan and delayed phase scan at 60–90 s.[39] It is also the technique of choice for identifying post-procedural complications such as pulmonary vein stenosis, atrio-oesophageal fistulae, or pericardial effusions.

Myocardial scar location identified by delayed enhancement cardiac CT has also been shown to correlate well with invasive electroanatomic mapping defined VT scar substrate. This, combined with the detailed cardiac anatomy that cardiac CT provides, may facilitate planning of electroanatomic mapping procedures and through procedural image integration may also facilitate more targeted and safer VT ablation.[40,41]

Valvular heart disease

Valvular heart disease is a frequent underlying cause of heart failure and echocardiography is the gold standard for its diagnosis and ongoing surveillance and to assess its effect on the ventricular performance. Cardiac CT has been shown to have good correlation with echocardiography parameters in the assessment of valvular heart disease and can be used for patients in whom echocardiographic images are found to be inadequate.[8]

In aortic stenosis, the measurement of aortic valve calcification provides prognostic value beyond clinical and Doppler echocardiographic evaluation alone.[42] In the current ESC guidelines, severe aortic valve calcification along with a rate of progression of peak transvalvular velocity of ≥0.3 m/s/year in patients with asymptomatic severe aortic stenosis is now a recognized indication for surgical aortic valve replacement

(Class IIa indication). Severe aortic stenosis is likely when the aortic valve calcium score on cardiac CTA is ≥2000 AU in men and ≥1200 AU in women.[43] Cardiac CTA has also now become essential in the pre-procedural workup for patients being considered for transcatheter aortic valve replacement and the newer transcatheter mitral valve replacement. Here, it can effectively evaluate the valvular morphology and its related structures in high detail to determine anatomical suitability for various valve sizes and to minimize complications (*Figure 8*).[44] Although cardiac CT can be of use in patients with aortic regurgitation and mitral stenosis, its use here is restricted owing to superior information available by alternative imaging techniques.

Left ventricular assist devices

A significant number of patients with heart failure do not improve despite optimal medical/device therapy. Due to a finite amount of suitable donor hearts and ageing population, not every patient with refractory heart failure will be suitable for a cardiac transplant. A viable alternative therapeutic option for these patients may be mechanical circulatory support through the use of left ventricular assist devices (LVADs). Cardiac imaging modalities like echocardiography and cardiac CTA are vital cornerstones in the management of LVADs. In the early post-operative period of LVAD insertion, imaging with echocardiography is often limited due to the presence of effusions, dressings, patient positioning, and reverberation artefacts. CMR is contraindicated with LVADs. Hence, cardiac

Figure 8 Cardiac computed tomography scan showing the presence of a transcatheter mitral valve within the mitral valve annulus (white arrow). LA denotes left atrium and LV denotes left ventricle.
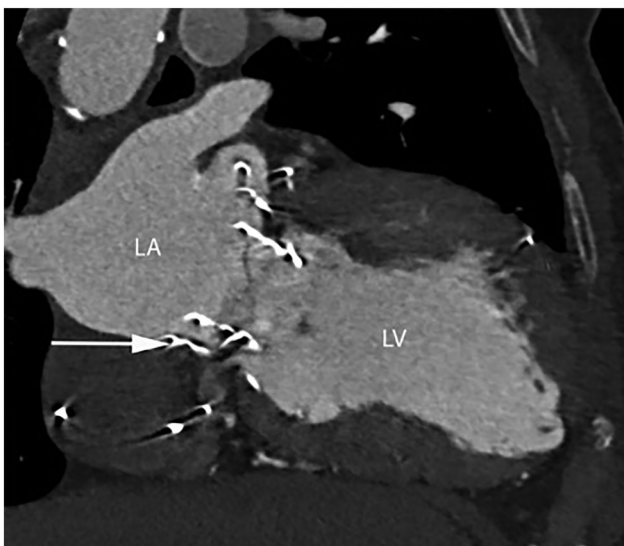
CTA provides an opportunity to non-invasively evaluate for device function and complications.

It enables detailed visualization of the inflow and outflow components of the LVAD and confirmation of adequate positioning of the cannulae along with recognition of complications such as insertion site haematomas and cannula thrombosis. In a small retrospective study involving 28 patients, Raman *et al.* found the sensitivity and specificity of CT for detecting cannula thrombosis and malposition to be 85% and 100%, compared with intra-operative findings.[45]

Cardiac CTA can be used to confirm whether an LVAD is functioning normally, for example, slightly leftward deviation of the interventricular and interatrial septum and closed aortic valve during systole are findings indicating normal device function. First pass contrast-enhanced dynamic cardiac CTA may also be used to calculate cardiac output in patients with LVADs with good agreement with Swan–Ganz thermodilution-derived cardiac output measurements.[46]

Right ventricular failure post-LVAD implantation remains a common and major cause of morbidity and mortality. Because CT is not as limited compared with other cardiac imaging modalities like echocardiography, it remains an invaluable assessment tool in this setting. In a study by Garcia Alvarez *et al.*, multiphase ECG-gated CT compared favourably against echocardiography in the measurement of RV volume and function with highly reproducible results.[47]

Cardiac transplantation

Cardiac transplantation remains a treatment of choice for many patients with end-stage heart failure with improving early transplant survival.[48] Cardiac allograft vasculopathy (CAV) is an important complication that may develop in cardiac transplant recipients. In patients who survive to 1, 5, and 10 years, CAV affects 8%, 30%, and 50%, respectively.[49] It is an aggressive form of CAD caused by diffuse coronary intimal hyperplasia, which can lead to ischaemia-driven graft failure, arrhythmias, and sudden death.

Early CAV detection is important because focal stenoses can be treated with percutaneous coronary intervention, and immunosuppressive therapy can be modified to control the disease. The preferred techniques to visualize the disease is by intravascular ultrasound (IVUS) and optical coherence tomography in conjunction with ICA. The diffuse, longitudinal, and concentric nature of the disease can necessitate the use of IVUS or optical coherence tomography above ICA alone, as ICA can detect focal stenoses but is unable to detect the hallmark of CAV, that is, diffuse intimal thickening. However, the invasive nature of these investigations (with the inherent risks) is an obvious drawback and provides an opportunity for a non-invasive imaging modality like coronary CTA to bridge this gap.

Table 2 Radiation doses and procedural times of various cardiac imaging modalities for typical patients

Imaging modality	Effective dose (mSv)	Pt on table (min)[a]
Coronary artery calcium score CT	1–2	5–7
Cardiac CTA	5.9[51]	10–12
Echocardiogram	No radiation	40
SPECT MPS	9–35[57]	20–40
CMR	No radiation	45–50
Invasive coronary angiography	5.6[58]	20–40
FFR-CT	No additional radiation	Not required

CMR, cardiac magnetic resonance; CT, computed tomography; CTA, computed tomographic angiography; FFR-CT, fractional flow reserve by coronary computed tomography; SPECT, single photon emission tomography.
[a]Times reflect experience at the authors' institution.

Functional tests rely on the presence of haemodynamically significant stenotic lesions to detect the presence of CAV and therefore lack the ability to sensitively detect diffuse intimal hyperplasia. Owing to the ability of coronary CTA to detect luminal stenoses severity as well as arterial wall morphology, it may be considered a good first choice test for detecting CAV. A meta-analysis published in 2014, involving 615 patients, showed pooled sensitivity of 97% and specificity of 81% for luminal irregularities; and for patients with stenoses >50%, sensitivities and specificities were 94% and 92%, respectively. Among studies comparing 64-slice coronary CTA against IVUS, overall sensitivities and specificities were 81% and 75%.[50]

Limitations of cardiac computed tomography

Although cardiac CT has a potential role in the imaging of patients with heart failure, it is an imaging technique that involves ionizing radiation dose exposure. This on average is 5.9 mSv in the UK for coronary imaging alone with a further 25% additional exposure for retrospective ECG-gated studies that incorporate tube current modulation.[51] Because image acquisition is based upon ECG gating, cardiac and coronary motion artefact can be troublesome in the presence of

significant cardiac arrhythmias or tachycardia. The technique itself requires patients to lie supine for the duration of their scan that may be problematic for patients with congestive cardiac failure and significant orthopnoea. This time however is substantially shorter than those times required for other cardiac imaging modalities (*Table 2*). Appropriate preparation requires knowledge of prior reactions to iodine-based contrast agents and the baseline renal function to prevent the advent of contrast-induced nephropathy. Local guidelines should be followed with respect to mitigating this risk.

Conclusions

Echocardiography will remain the front-line investigation for heart failure owing to its accessibility, versatility, and portability. Where more detailed information on ventricular performance or myocardial characterization is required, CMR imaging has already become established as a gold standard test. In a short time frame, cardiac CT has shifted its boundaries from being a test for coronary disease alone to one that has relevance for an array of other cardiac conditions. The strengths of cardiac CT in providing high image resolution at an affordable cost, in a quick time frame and at ever declining ionizing radiation, have enabled it to gain relevance in patients with heart failure. Here, its ability to achieve an accurate diagnosis and to facilitate appropriate treatment will become even more important in improving clinical outcomes for the future.

Disclaimer

Concepts and information presented are based on research and are not commercially available. Due to regulatory reasons, the future availability cannot be guaranteed.

Conflict of interest

None to declare.

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