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Corresponding author

Jin Hur, MD, PhD
 Department of Radiology,
 Severance Hospital, Yonsei University
 College of Medicine, 50 Yonsei-ro,
 Seodaemun-gu, Seoul 03722, Korea
 Tel: 82-2-2228-7400
 Fax: 82-2-393-3035
 E-mail: khuhz@yuhs.ac

Technological Improvements in Cardiac Thrombus Diagnosis

Jin Hur, Yoo Jin Hong, Dong Jin Im, Hye-Jeong Lee,
 Young Jin Kim, Byoung Wook Choi,

Department of Radiology, Severance Hospital, Yonsei University College of Medicine, Seoul, Korea

Cardiovascular imaging technology constantly evolves and provides more testing options for evaluating cardiovascular morphology and function. Accurate detection and diagnosis of cardiac thrombi are important in clinical practice, as they provide a substrate for embolic events and a rationale for anticoagulation therapy. Echocardiography, predominantly transesophageal echocardiography, has been used as a reference modality to assess flow stasis and cardiac thrombus. Cardiac computed tomography (CCT) and cardiac magnetic resonance imaging (CMRI) have also been proposed and tested as alternative imaging modalities for cardiac thrombus detection. Given the noninvasive nature of CCT and CMR, developing strategies based on these modalities for the detection of cardiac thrombi and flow stasis is of great clinical interest. However, these advanced imaging techniques should add value in the clinical setting.

Key words Echocardiography · Computed tomography · Magnetic resonance imaging · Heart · Thrombus.

INTRODUCTION

Visualization of anatomic and pathological conditions within the heart, using noninvasive means, is fundamental for understanding, diagnosing, and treating cardiovascular diseases. Cardiovascular system imaging is technically challenging; it is not surprising that cardiovascular applications have often been a driving force in the ongoing evolution of imaging technologies.

Atrial fibrillation (AF) is a major independent risk factor for stroke, and the risk increases in patients with AF and other concomitant potential cardiac sources of embolism [1-4]. Thus, accurate detection and diagnosis of high-risk embolic sources, such as cardiac thrombi, is important, as they provide a substrate for embolic events and a rationale for anticoagulation therapy. For almost 2 decades, the gold standard for assessing flow stasis and thrombi in the heart has undoubtedly been echocardiography, predominantly transesophageal echocardiography (TEE) [5-7]. Intra-cardiac echocardiography (ICE) and TEE evolved from transthoracic echocardiography (TTE) as an approach that uses high-frequency transducers with improved spatial resolution. Cardiac computed tomography (CCT) and cardiac magnetic resonance imaging (CMRI) have also been proposed and tested as alternative imaging modalities for cardiac thrombus

detection [8-13]. More recently, new imaging techniques, such as dual-energy CT (DECT), have been developed and tested to assess flow stasis and cardiac thrombi [14].

In this article, we describe the pathophysiology of thrombus formation. We introduce recent technical advances in cardiovascular imaging in the fields of echocardiography, CT, and MRI as approaches to evaluate flow stasis and cardiac thrombus. We also discuss advantages and disadvantages of the available imaging modalities for cardiac thrombus assessment.

CARDIAC THROMBUS

LAA function and thrombus formation

Anatomically, the left atrial appendage (LAA) is highly variable, and consists of a blind-ended pouch with tapering edges and trabeculations from the pectinate muscles. This morphology promotes stasis and thrombus formation. The shape of the LAA can correlate with different risks of thrombus formation and stroke, although this remains controversial; a few studies have shown that extensive trabeculations are associated with stroke [15,16].

Normal contraction of the LAA during sinus rhythm and adequate blood flow within the LAA lower the risk for thrombus formation within the cavity. Thrombus formation is more likely to occur within the LAA in cases with reduced contractility and stasis. During AF, there is a decrease in LAA contrac-

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tility and function, which manifests as a decrease in Doppler velocities and LAA dilatation [17]. The remodeling processes associated with AF causes the LAA to function as a static pouch, predisposing the heart to stagnation and thrombosis. AF results in structural remodeling changes in the LAA, especially chamber enlargement. The average LAA volume is more than 3 times larger in AF patients, compared with patients in sinus rhythm [18]. Other structural LAA changes those in AF include luminal surface area enlargement, a smoother endocardial surface, and a higher degree of endocardial fibroelastosis, all of which can all contribute to thrombus formation [18,19].

LA or LAA thrombus

The left atrium (LA) and the LAA are important locations that are frequently associated with thrombus formation and subsequent cardioembolic events, particularly in association with dysrhythmias, such as AF [20,21]. An estimated 47% of thrombi in valvular AF and 91% of those in nonvalvular AF are located in the LAA [22]. Therefore, current research is focused on the LAA to better understand its anatomy, physiology, and to test various imaging modalities and techniques to assess the shape and size, blood flow patterns, and for the presence or absence of thrombi. Cardiac thrombi of the LA or LAA are common causes of stroke, and because the LA and LAA thrombi are treatable sources of embolism, thrombi detection may significantly affect patient management.

LV thrombus

Left ventricular (LV) thrombi can occur in LV dysfunction, especially in the acute stage after myocardial infarction (MI)

[23,24]. LV thrombi are clinically important because of their ability to embolize [25,26]. In fact, patients who develop mural thrombi after MI have a poor prognosis, including a 10% rate of systemic embolization [27]. Early detection of LV thrombi is critical because it allows for early initiation of anticoagulation therapy to reduce the likelihood of embolization [28].

Right heart thrombus

Right heart thrombus (RHT) in the absence of structural heart disease, atrial fibrillation, or a cardiac catheter is rare. The majority of thrombi originates from the deep venous system and embolize to the right heart as precursors of a pulmonary embolism (PE) [29]. Clinical consequences of RHT depend upon the clot size and overall clot burden. Thrombi in the right side of the heart may become infected or cause a PE. Sudden cardiovascular collapse is the worst possible outcome if the clot compromises the cardiac or pulmonary circulation. The overall mortality rate in patients with RHT has been reported as 28% and as high as 100% in untreated patients [30,31]. It is important to diagnose an RHT, because it can embolize at any moment, which would then require emergency treatment, and this type of embolism is associated with a high mortality rate.

IMAGING MODALITIES

Echocardiography

Initial studies that use TTE have a limited ability for detecting LA and LAA thrombus formation [7,32]. However, harmonic imaging and the administration of ultrasound contrast agents have enhanced the ability of TTE to detect LAA thrombi [33,34].

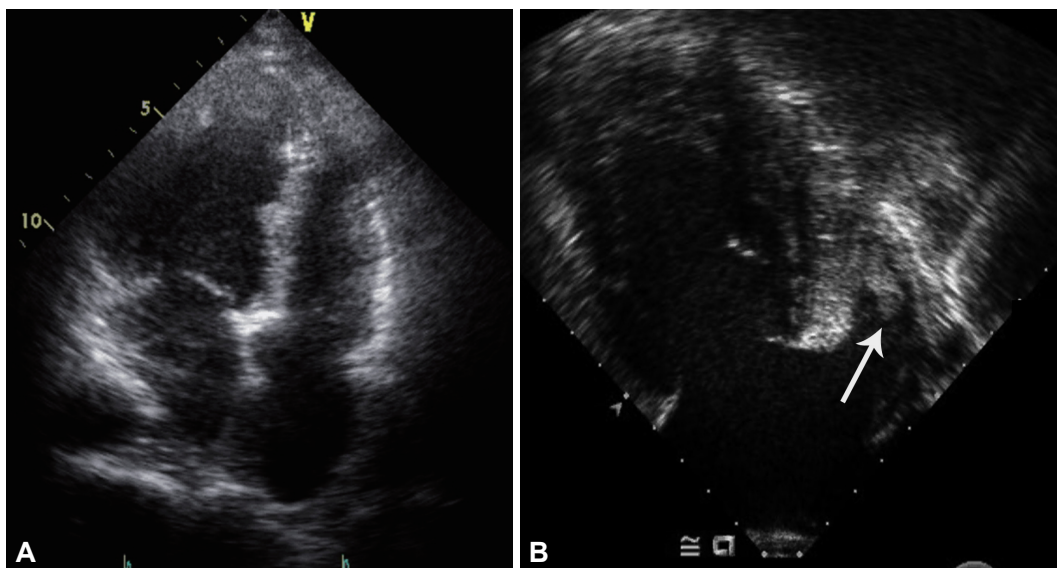


Fig. 1. Images from a 45-year-old man with stroke and atrial fibrillation. (A) 4-chamber TTE image shows no thrombus in the LA. (B) TEE image reveals a small echogenic thrombus (arrow) in the LAA. LA: left atrium, LAA: left atrial appendage, TEE: transesophageal echocardiography, TTE: transthoracic echocardiography.

Because of the superior visualization of posterior structures, such as the LA and LAA, compared with TTE, TEE has been shown to be effective for assessing thrombi in the LA and LAA (Fig. 1) [35,36]. Therefore, TEE is currently the most widely-used method and is accepted as the reference modality for diagnosing and excluding the presence of LAA thrombi. However, TEE is a semi-invasive procedure that requires special skills for proper execution and interpretation. A prospective study reported 100% sensitivity [95% confidence interval (CI): 74–100%], 99% specificity (95% CI: 97–99.9%), and 100% negative predictive value (NPV) (217/217), but only an 86% positive predictive value (PPV) (12/14) for a population with a 5.2% thrombi prevalence [36]. The investigators suggested that this low PPV resulted from trabeculations or pectinate muscles in the LAA being misinterpreted as thrombi by inexperienced observers.

One drawback of TEE is that it has limited sensitivity for identifying small thrombi or thrombi within a side lobe. Thus, the absence of LAA thrombus visualization does not always equate with the absence of an LAA thrombus. Functional assessment of the LAA using Doppler echocardiography is widely-used to better assess the LAA and the risk of thromboembolism. LAA blood flow velocity measurement allows a more-quantifiable assessment of spontaneous echo contrast (SEC) than grades of severity, which are primarily based on echogenicity. Decreasing LAA velocities were strongly associated with increasing grades of SEC severity in the LA and LAA, and with embolic events [37].

The use of three-dimensional (3D) TEE imaging is a relatively recent development that improves assessment of LAA anatomy. Although two-dimensional (2D) TEE provides higher-resolution images, because of a better frame rate, 3D TEE allows a more comprehensive assessment of the LAA and overcomes some of the limitations associated with 2D imaging, such as in-

adequate imaging planes. In addition, 3D TEE provides better separation and differentiation between adjacent structures, along with a more complete and comprehensive evaluation of the LAA, its complex morphology, and the surrounding structures [38]. There are still limited data regarding the sensitivity and specificity of 3D TEE for detecting LAA thrombi. However, 3D TEE has become an important tool for guiding therapeutic devices into the LAA with recent advances in percutaneous devices for LAA closure.

ICE can be used as an alternative imaging method to TEE to assess LAA flow stasis and thrombus formation. ICE can provide multiple views and detailed LAA imaging which facilitates detection of potential thrombi [39,40]. Although ICE is less sensitive than TEE for thrombus detection [41], it can serve as a complementary method, especially when equivocal TEE findings merit further evaluation. However, because ICE is an invasive procedure, it is not typically used in daily practice and is mainly reserved for planned interventional cardiac procedures in a catheterization laboratory setting.

2D TTE was the first imaging modality for visualizing LV thrombi [42]. 2D TTE has been reported to have sensitivity rates of 92% to 95% and specificity rates of 86% to 88% [43,44]. Despite its high diagnostic accuracy, TTE can be technically challenging, as echocardiographic findings of the LV thrombus may be subtle and, consequently, easily missed. The disadvantages of TTE include difficulty in discerning the myocardium-thrombus interface, limited near-field resolution of the apex, and difficulty in obtaining images of the true apex. As a result, small non-protruding mural thrombi may resemble a normal or mildly thickened LV wall, and normal structures, such as papillary muscles, anomalous bands, and trabeculae may mimic thrombi. TEE has been shown to be better suited than TTE for detecting intra-atrial

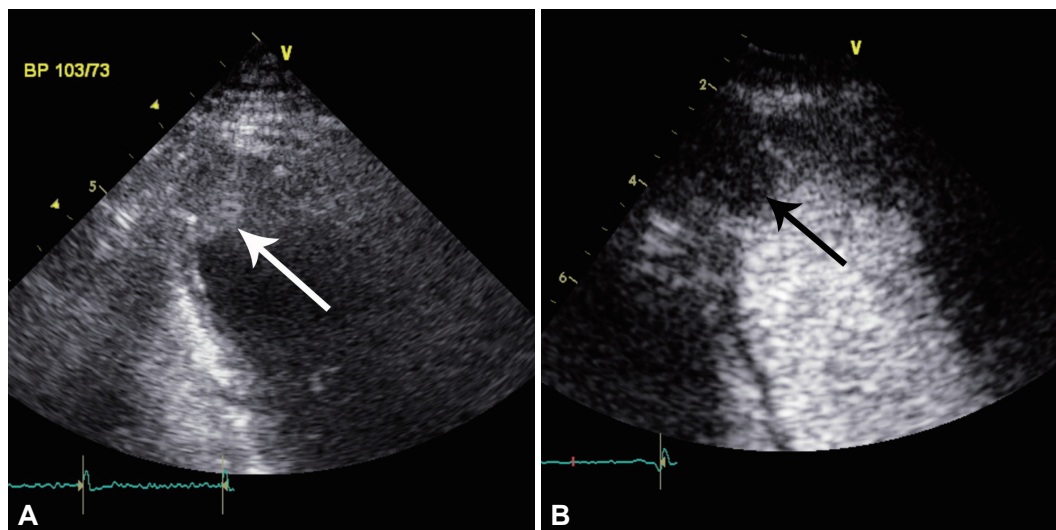


Fig. 2. Image from a 68-year-old man with stroke and myocardial infarction. (A) TTE image shows a suspicious echogenic thrombus (arrow) in the LV apex. The thrombus evaluation was difficult because of poor acoustic windows. (B) TTE with contrast agent shows a small thrombus (arrow) in the LV apex. TTE: transthoracic echocardiography, LV: left ventricle.

thrombi, but its value in the diagnosis of LV thrombus has not been extensively explored [45,46]. A previous study has shown that when TTE and TEE are used to detect or exclude the LV thrombus, the results may be inconclusive in as many as 46% (87/190) of patients [47]. However, advanced techniques, such as harmonic imaging and the use of intravenous echocardiographic contrast agents, may improve the overall diagnostic image quality [48]. Thus, LV echocardiographic contrast agents have been used to increase the accuracy of LV thrombus detection, especially in patients with difficult acoustic windows (Fig. 2).

TTE is usually considered as a screening test for diagnosing right heart thrombi. TTE may demonstrate right ventricular dysfunction, tricuspid regurgitation, and leftward atrial septal bowing in patients with pulmonary thromboemboli. However, direct visualization of the thrombus located in the pulmonary arteries or entrapped in the right atrium is difficult. In contrast, TEE not only detects the thrombus in the heart with higher accuracy, it may also allow PE to be diagnosed, and is associated with 80% sensitivity and 100% specificity in patients with suspected massive pulmonary emboli [49]. TEE can also provide information about the presence of a right-to-left shunt through a patent foramen ovale.

Cardiac computed tomography

A non-invasive method for identifying intracardiac thrombus with high reliability and accuracy, comparable to TEE, would be of significant clinical value. CCT is a well-established, but not widely-used technique for cardiac thrombus imaging. CCT can be used to detect intracardiac thrombus with high diagnostic accuracy (Fig. 3) [8-11,50,51]. A recent meta-analysis demonstrated

that the overall high accuracy of cardiac CT, compared with TEE, can be used to detect LA or LAA thrombus in patients with AF. The investigators included 19 studies with a total of 2955 patients and found the weighted mean sensitivity and specificity to be 96% (95% CI: 92–100%) and 92% (95% CI: 91–93%), whereas the PPV and NPV were 41% (95% CI: 37–44%) and 99% (95% CI: 99–100%), respectively [52]. This is because a pseudo-filling defect, such as flow stasis, can also cause an apparent filling defect on CT images, thereby mimicking a thrombus. Because CCT identifies a cardiac thrombus based on anatomic appearance, it can be challenging to differentiate between thrombus and flow stasis.

The flow stasis phenomenon appears when LA dysfunction causes incomplete mixing of contrast agent and blood. Therefore, delayed phase scanning would allow for complete mixing of contrast agent and blood (Figs. 4 and 5) [53,54]. In a sub-analysis of 753 patients from a recent meta-analysis with available delayed imaging data, the PPV increased significantly to 92%, while maintaining a high NPV of 100% and an overall diagnostic accuracy of 99% (95% CI: 98–100%) [52]. These results suggest that cardiac CT using delayed imaging is a reasonable alternative to TEE to evaluate LAA or LA thrombus and to differentiate thrombus from flow stasis.

Although delayed imaging with cardiac CT has excellent sensitivity and specificity for thrombus, it requires rescanning within 1 minute. Since this would double the radiation exposure, prior knowledge of or a high suspicion of LA or LAA thrombus would be required before patients would be subjected to this procedure. Therefore, radiation exposure is a significant disadvantage of cardiac CT for LAA evaluation. However, CT has recent-

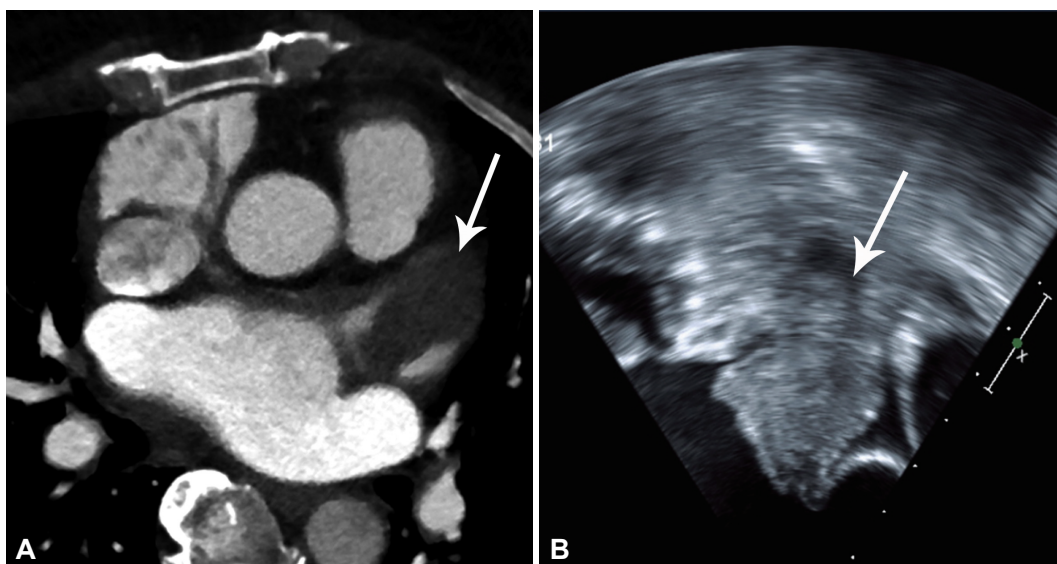


Fig. 3. Images from a 62-year-old woman with atrial fibrillation. (A) Axial cardiac CT imaging shows an oval filling defect (arrow) in the LAA. (B) TEE imaging demonstrates an oval-shaped echogenic thrombus (arrow) in the LAA. LAA: left atrial appendage, TEE: transesophageal echocardiography.

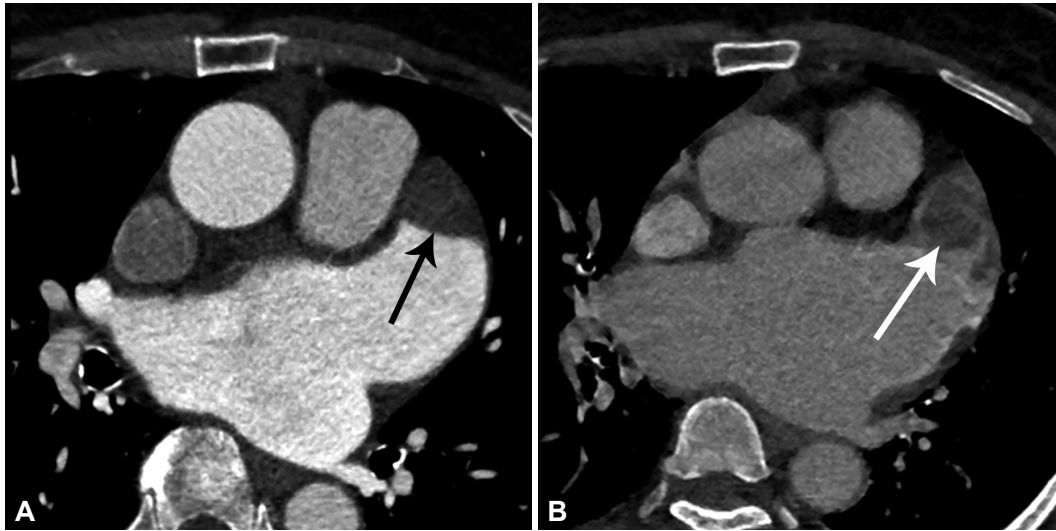


Fig. 4. Images from a 65-year-old woman with stroke and atrial fibrillation. (A) Axial early-phase cardiac CT imaging shows a triangular filling defect (arrow) in the LAA. (B) Axial late-phase cardiac CT imaging shows a round-shaped thrombus (arrow) in the LAA. LAA: left atrial appendage.

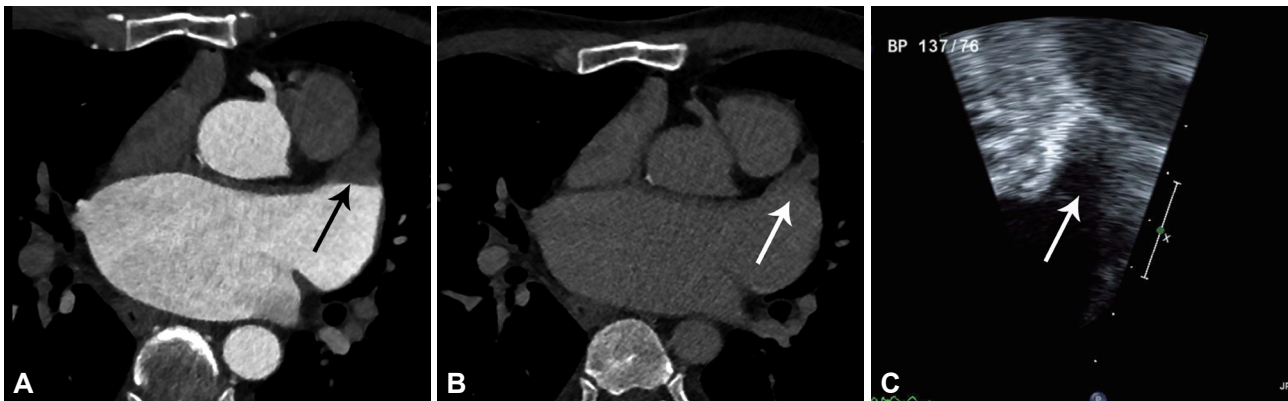


Fig. 5. Images from a 41-year-old man with stroke and atrial fibrillation. (A) Axial early-phase cardiac CT image displays a triangular filling defect (arrow) in the LAA. (B) Axial late-phase cardiac CT image shows no filling defect (arrow) in the LAA. The defect caused by blood stasis disappeared during late-phase imaging. (C) TEE image demonstrates moderate spontaneous echo contrast (arrow) with no thrombus in the LAA. LAA: left atrial appendage, TEE: transesophageal echocardiography.

ly undergone technical and acquisition changes that substantially reduce the dose of radiation [55].

Recent advancement in CT technology enabled DECT to generate material-specific images based on the atomic number Z and the unique mass attenuation coefficient of a particular material at different X-ray energies [56,57]. Material-specific images provide qualitative and quantitative information about tissue composition and contrast media distribution. The most significant contribution of DECT-based material characterization comes from the capability to assess iodine distribution by creating an image that exclusively shows iodine. These iodine-specific images increase tissue contrast and amplify subtle attenuation differences between normal and abnormal tissues, improving lesion detection and characterization. The DECT technique permits the differentiation of iodine from other materials by the material decomposition method [58]. This is valuable for

differentiating iodine-enhancing lesions, such as flow stasis or tumors, from non-enhancing lesions including thrombus (Figs. 6 and 7). Early experiences with dual-energy CCT for detecting thrombi and blood flow stasis in 63 stroke patients demonstrated that the overall sensitivity and specificity were 97% (95% CI: 82–100%) and 100% (95% CI: 86–100%), respectively. In addition, the PPV was 100%, while maintaining a high NPV of 97% [14]. This result suggests that DECT has the potential to detect LAA thrombus and distinguish thrombus from flow stasis. Another study of dual-energy CCT in 37 patients with cardiac masses demonstrated that the iodine concentration could be feasibly quantified from DECT data and used to differentiate cardiac myxomas from thrombi. Based on these results, the quantified values of the mean iodine concentration (mg/mL) were significantly higher in cardiac myxomas compared to cardiac thrombi (3.53 ± 0.72 vs. 1.37 ± 0.31 , respectively, $p < 0.001$) [59]. This study also supported

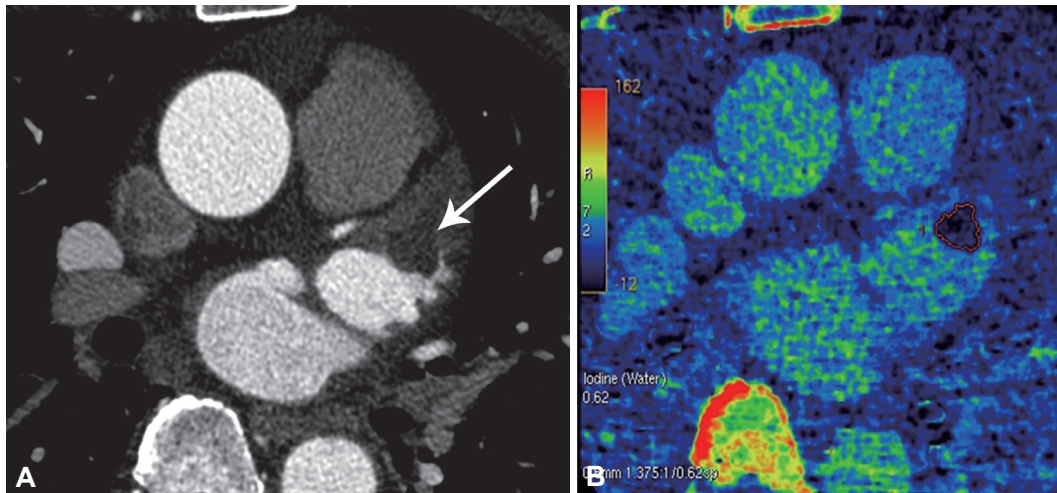


Fig. 6. Images from a 52-year-old man with stroke and thrombus. (A) Axial cardiac CT shows an oval filling defect (arrow) in the LAA. (B) Axial dual-energy CT iodine map reveals a filling defect in the LAA; the mean iodine concentration within the ROI was 0.66 mg/mL. LAA: left atrial appendage, ROI: region of interest.

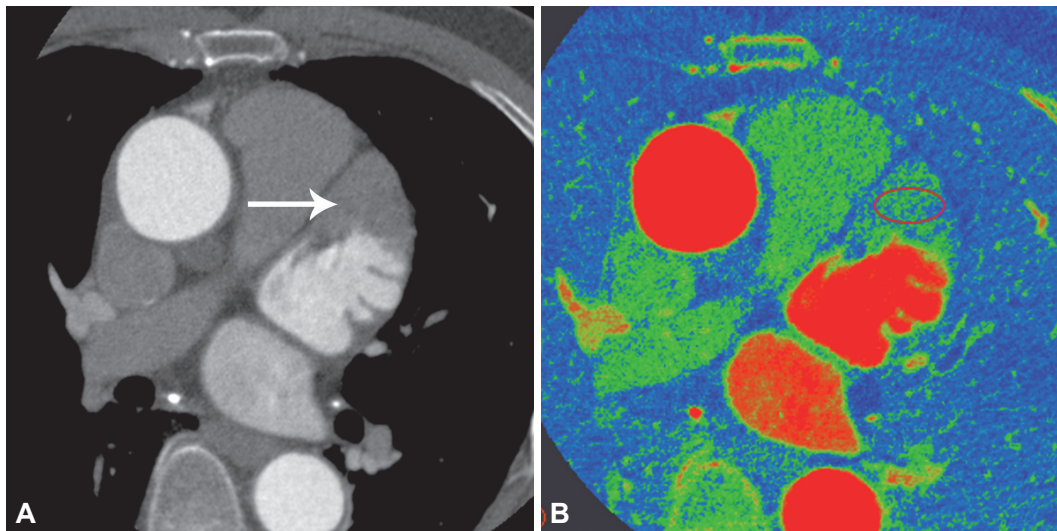


Fig. 7. Images from a 58-year-old man with atrial fibrillation and flow stasis. (A) Axial cardiac CT shows a triangular filling defect (arrow) in the LAA. (B) Axial dual-energy CT iodine map reveals a filling defect in the LAA; the mean iodine concentration within the ROI was 3.36 mg/mL. LAA: left atrial appendage, ROI: region of interest.

that dual-energy CCT using a quantitative analytic methodology can be used to differentiate and characterize iodine-enhancing and non-enhancing lesions.

Prognosis assessment is very important for therapeutic options and approaches in patients with pulmonary thromboembolism. Several studies reported that patients with RHT and PE had worse prognoses than control groups [60,61]. The International Cooperative Pulmonary Embolism Registry demonstrated that among patients with acute pulmonary thromboembolism, RHT was a marker of worse prognosis in initially apparently stable patients treated with heparin alone [61]. In this respect, CCT can be used to simultaneously diagnose RHT in patients with acute pulmonary thromboembolism. However, there are not currently any data on contrast media administration or stan-

dard scanning protocols.

Cardiac magnetic resonance imaging

Important advances have been made in rapid MR imaging technology and its application for cardiovascular imaging during the past decade. Clinical high-field strength magnets, high-performance gradient hardware, and ultrafast pulse sequence technology are rapidly improving CMR imaging examination.

CMR imaging can be used to evaluate potential sources of emboli, such as LAA thrombi or LV thrombi [62-64]. Several studies have reported that CMR has high reproducibility and high sensitivity for detecting LAA thrombus, compared to TEE [62,63]. Diagnostically, CMR imaging is potentially more advantageous, compared with echocardiography because of its

ability to characterize the myocardium, in addition to providing cine imaging (cine-CMR). However, one of the drawbacks of CMR is that it is far from an ideal modality as it has limited spatial resolution and susceptibility to slow flow, which can create artifact-mimicking, space-occupying lesions. Spatial resolution and image contrast between the background and LA and LAA wall, as well as slow flow within the LA and LAA, can affect the 3-dimensional contrast-enhanced CMR thrombus evaluation [63]. Imaging artifacts are also commonly encountered in cine-CMR; these include breathing motion, flow-related, and inhomogeneity artifacts.

Recent advances in sequence development, combined with the ability of paramagnetic contrast agents to enhance the ventricular blood pool, provide delayed enhancement (DE)-CMR with a potential advantage for detecting LA or LV thrombi (Fig. 8). DE-CMR, is widely-used to discern viable from infarcted myocardia, and a thrombus can be identified by the absence of contrast en-

hancement. DE-CMR has been validated as an accurate technique for thrombus detection based on comparisons with pathological findings and clinical embolic events [13,64-66]. Because DE-CMR identifies a thrombus based on tissue characteristics rather than anatomic appearance, it allows a thrombus to be delineated from the myocardium and chamber cavity irrespective of location or morphology. A previous study reported that, among LV thrombi detected in 12 patients that used DE-CMR, 50% (6/12) were not detected by cine-CMR, and 58% (7/12) were not detected by echocardiography [13]. Another study reported that DE-CMR identified LV thrombi in 7% of subjects (55 patients), while cine-CMR identified thrombi in only 4.7% (37 patients). Among the 55 patients with LV thrombi discovered using DE-CMR, 44% (24/55) had prior cine-CMR analyses that were negative for thrombus [65]. This study validated the ability of long inversion time (TI) DE-CMR to detect LV thrombi and also showed the superiority of this technique over cine-CMR.

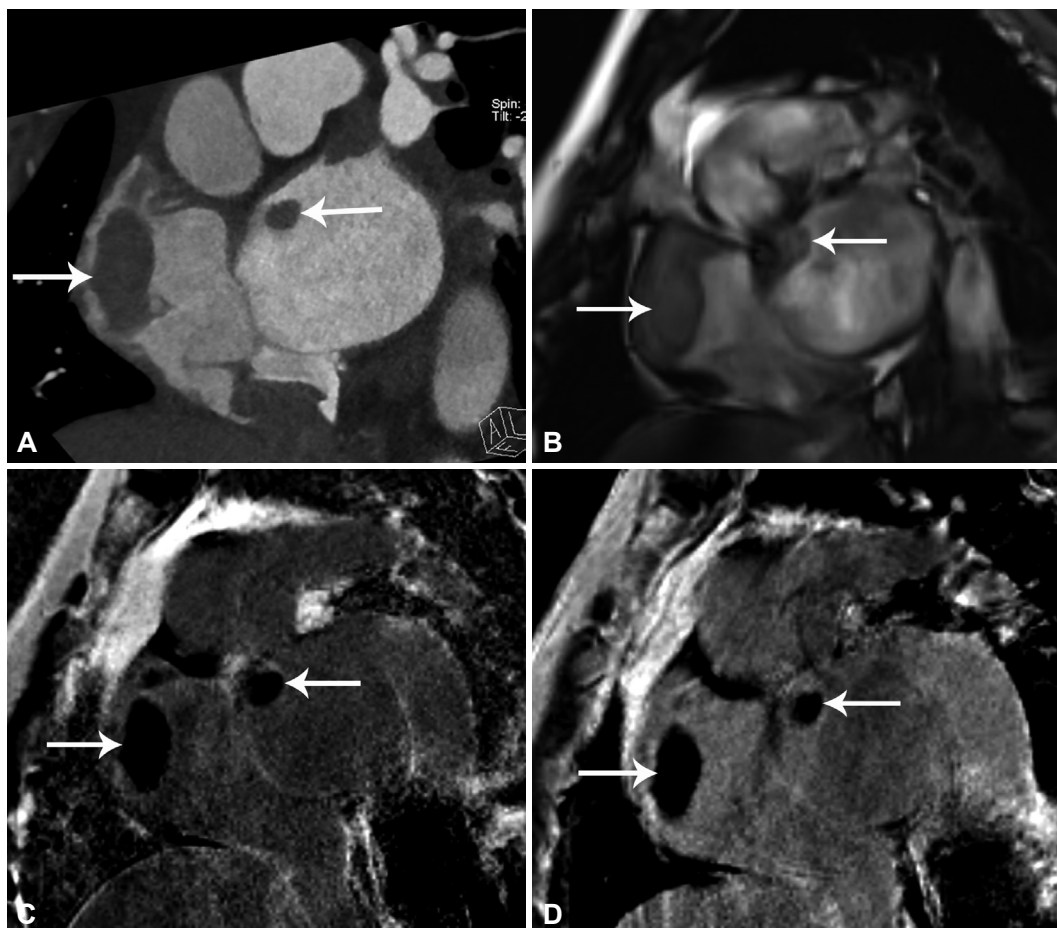


Fig. 8. Images from a 52-year-old woman with atrial fibrillation and dilated cardiomyopathy. (A) Oblique sagittal reformatted CT imaging shows multiple filling defects (arrows) in the RA and LA. (B) A short-axis cine-CMR image, using a balanced steady-state free precession sequence, shows multiple masses (arrows) with iso-signal intensity compared to that of the left ventricular myocardium in the RA and LA. (C) On short-axis standard DE-CMR [inversion time (TI), 220 msec], the masses showed black signal intensity without delayed enhancement (arrows). (D) On short-axis DE-CMR with long DE-CMR (TI, 400 msec), the masses showed black signal intensity without delayed enhancement (arrows). The masses were confirmed as thrombi which were resolved on follow up transesophageal echocardiography after anticoagulation therapy. RA: right atrium, LA : left atrium, CMR: cardiac magnetic resonance, DE-CMR: delayed enhancement-CMR.

Furthermore, the thrombus prevalence increased with worsening LV ejection fraction, ischemia etiology, and myocardial scarring. Therefore, the established capabilities of CMR imaging in coronary artery disease are of additional value when characterizing a suspected thrombus.

A recent meta-analysis compared the diagnostic ability of TTE without contrast, TTE with contrast, cine-CMR, and DE-CMR to detect LV thrombi [67]. The investigators included 7 studies with a total of 803 patients and demonstrated that DE-CMR imaging was the most accurate modality for detecting LV thrombi (sensitivity 88%, specificity 99%), followed by cine-CMR imaging (sensitivity 58–79%, specificity 99%, accuracy 95%, PPV 93–95%, NPV 95–96%), contrast TTE (sensitivity 23–61%, specificity 96–99%, accuracy 92%, PPV 93%, NPV 91%), and, finally, non-contrast TTE (sensitivity 24–33%, specificity 94–95%, accuracy 82%, PPV 57%, NPV 85%). In this meta-analysis, they were not able to demonstrate differential diagnostic accuracy among the different modalities because of the small number of studies and variable usage of gold standards.

A recent study evaluated the diagnostic performance of a comprehensive multicomponent CMR for assessing LA/LAA thrombus in 261 patients with AF that were referred for pulmonary vein isolation [68]. Long TI DE-CMR had the best diagnostic accuracy out of the CMR sequences that were investigated (99.2%; 95% CI: 97.2–99.9%), sensitivity (100%; 95% CI: 66.4–100%), specificity (99.2%; 95% CI: 97.2–99.9%), PPV (81.8%; 95% CI: 48.2–97.7%), and NPV (100%; 95% CI: 98.5–100%). In contrast, cine-CMR had the lowest diagnostic accuracy at 91.6% (95% CI: 87.5–94.6%), sensitivity of 66.7% (95% CI: 29.9–92.5%), specificity of 92.5% (95% CI: 88.5–95.4%), and a PPV of 24% (95% CI: 9.4–45.1%). All of the CMR sequences had a high negative predictive value, ranging from 98.7% by cine-CMR to 100% by long TI DE-CMR. This was likely because long TI DE-CMR provided adequate coverage of the entire LA and LAA and was less susceptible to artifacts. Furthermore, the situation of an under filled LAA could also be avoided, as it was performed with a single-shot technique in the equilibrium phase, 10 min after contrast administration. In addition, due to the rapid acquisition time of this technique, breath-holding was not required. The processes could also be performed in conditions with irregular cardiac rhythm, which is common in patients with AF.

Myocardial longitudinal relaxation time measurement (T1 mapping) with gadolinium contrast-enhanced inversion recovery-prepared sequences has emerged as a novel approach for noninvasive quantification of myocardial fibrosis. T1 mapping consists of quantifying the T1 relaxation time of a tissue, using analytical expressions of image-based signal intensities. A fundamental principal of MR imaging is that the signal intensity of pixels is based on the relaxation of hydrogen nuclei protons in a static magnetic field [69,70]. The T1 relaxation times of two

tissues vary substantially. Edema, fat infiltration, and fibrosis also cause differences in T1 relaxivity. Qualitative sequences rely on the use of arbitrary signal intensity scales for T1 and T2 values with interpatient and inter-image variability, whereas myocardial mapping offers the potential to produce images that have standardized, reproducible scales, similar to the attenuation values used for CT [71,72]. Although T1 mapping is currently expanding as a means for depicting diffuse interstitial fibrosis in a variety of cardiac diseases, this technique is rarely used for focal cardiac disease. A few studies have investigated the use of T1 or T2 mapping for evaluating cardiac masses [73,74]. A recent study compared the post-contrast T1 time derived from T1 mapping using a TI scout (Lock-Locker sequence) for 15 tumors and 15 thrombi [73]. As expected, the T1 time was significantly shorter in tumors than in thrombi (383 ± 84 ms vs. 477 ± 139 ms, $p=0.03$). When a cut-off value of 422 ms was used as a diagnosis of thrombus, the sensitivity and specificity were 67% and 80%, respectively, with an area under the receiver-operating characteristic curve of 0.73 (95% CI: 0.54–0.92). Another recent study investigated T1 and T2 values in 22 patients with cardiac thrombus. According to their data, the native T1 of thrombi was 1037 ± 152 ms (vs. 1032 ± 39 ms for myocardium, $p=0.88$; vs. 1565 ± 88 ms for blood pool, $p<0.0001$). T2 were 74 ± 13 ms (vs. 51 ± 3 ms for myocardium, $p<0.0001$; vs. 170 ± 32 ms for blood pool, $p<0.0001$) [74].

CMR imaging is advantageous, compared with cardiac CT, due to the absence of radiation exposure and the avoidance of iodinated contrast media. However, in contrast to CT technology, the future of CMR in assessing cardiac thrombi and flow stasis is less certain. Given the noninvasive nature of CMR and the lack of ionizing radiation, developing strategies based on this modality for detection of cardiac thrombi and flow stasis is of great clinical interest.

CONCLUSION

The accurate detection and diagnosis of cardiac thrombi are important, as they provide a substrate for embolic events and a rationale for anticoagulation therapy. Substantial efforts have been made to improve the evaluation of flow stasis and thrombi detection. For almost 2 decades, the gold standard for assessing flow stasis and thrombus in the heart has undoubtedly been echocardiography, predominantly TEE. However, a non-invasive method with high reliability and accuracy comparable to TEE that is capable of identifying intra-cardiac thrombus or flow stasis would be of significant clinical value. Currently, CCT and CMRI have been proposed and tested as alternative imaging modalities. Given the noninvasive nature of CCT and CMR, developing strategies based on these modalities for the detection of cardiac thrombi and flow stasis is of great clinical interest. However, it must be shown that these advanced imaging techniques

yield added value in the clinical setting.

Conflicts of Interest

The author declare that they have no conflict of interest.

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