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Possibilities of computed and magnetic resonance imaging of the heart in patients with atrial fibrillation

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Abstract

Computed and magnetic resonance imaging of the heart has been widely used in recent years in patients with atrial fibrillation. They are used to determine the morphology of the heart, the presence of intracardiac thrombi, quantify the structures of the heart, thrombosis of intracardiac devices, determine tactics for surgical interventions, and other purposes. These methods of instrumental diagnostics can be used as an alternative to transesophageal echocardiography, which has a number of limitations and disadvantages compared to computed tomography and magnetic resonance imaging. Computed and magnetic resonance imaging of the heart are used to avoid invasiveness in the study of the heart, to improve the accuracy of measuring heart structures, to reduce the number of diagnostic methods used before various surgical interventions in patients with atrial fibrillation, and also, according to epidemic indications, as part of the prevention of the spread of coronavirus infection. In addition, magnetic resonance imaging allows to avoid radiation exposure to the patient. The review presents the results of studies, meta-analyses of pooled samples, as well as a description of the clinical possibilities of computed and magnetic resonance imaging of the heart in patients with atrial fibrillation. Publications on the use of these methods for visualization of thrombi in the left atrium and its appendage, in pulmonary vein ablation and occlusion of the left atrial appendage, as well as data on visualization of the residual flow around the occlusive device and thrombosis of intracardiac devices are presented. According to the results of a literature review, computed tomography and magnetic resonance imaging of the heart have similar or higher imaging capabilities compared to transesophageal echocardiography, as well as some advantages over it, primarily the non-invasiveness of the procedure. The works demonstrating the possibilities of computed tomography of the heart for the diagnosis of coronary heart disease in patients with atrial fibrillation are presented. In preparing the review, the literature search method in PubMed databases for the period 2013–2022 was used.

Keywords: cardiac CT, cardiac MRI, atrial fibrillation, thrombosis of the left atrial appendage, review.

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Abbreviations

IHD, ischemic heart disease; CT, computed tomography; PV, pulmonary veins; LA, left atrium; MRI, magnetic resonance imaging; LAA, left atrial appendage; AF, atrial fibrillation; TEE, transesophageal echocardiography; COVID-19, COronaVIrus Disease 2019.

Background. Atrial fibrillation (AF) is the most common cardiac arrhythmia in adults and is of great clinical and social significance. The current prevalence of AF in adults is 2%–4%. [1] In the future, it is expected to increase by 2.3 times because of increased life expectancy in the general population and the intensified search for undiagnosed arrhythmia [1]. AF causes a five-fold increase in the risk of stroke, with ischemic stroke or transient ischemic attack representing the first manifestation of AF in 2%–5% of patients [2]. The left atrium (LA) and LA appendage (LAA) are considered the main source of thromboembolism and stroke in patients with AF [3].

To rule out LA and LAA thrombi before cardioversion, LAA occlusion, pulmonary vein isolation, assessment of residual flow around the occlusive device, and exclusion of intracardiac device thrombosis in patients with AF, various instrumental diagnostic methods are used. The gold standard is transesophageal echocardiography (TEE) [4], and the sensitivity of this method in detecting an LA thrombus ranges from 92% to 100% [5]. TEE has several limitations and disadvantages (inclu-

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ding invasiveness, need for trained personnel, and presence of rare but potentially life-threatening complications); thus, alternative solutions to this diagnostic problem are needed.

This literature review considers the possibilities of noninvasive research methods such as computed tomography (CT) and magnetic resonance imaging (MRI) of the heart in patients with AF to visualize the LA/LAA, detect intracardiac thrombogenesis, and assess cardiac morphology before surgical interventions and some other clinical cases.

Noninvasive diagnostic methods in patients with AF have gained additional relevance in the context of the coronavirus disease 2019 pandemic [6]. The American Society of Echocardiography issued a statement on the protection of patients and medical personnel, which claimed that TEE bears an increased risk of spreading SARS-CoV-2 because of possible aerosolization of large amounts of the virus when coughing or vomiting during the examination. Under these circumstances, the potential benefit of TEE for a patient with suspected or confirmed COVID-19 and the risk of exposure to healthcare personnel should be carefully assessed.

In addition to the use of personal protective equipment, cancellation or postponement of TEE has been suggested if alternative imaging methods are available, such as transthoracic echocardiography, including ultrasound-enhanced agent, CT, or contrast-enhanced MRI. The use of these methods to avoid aerosolization procedures must balance the risk of transporting the patient through the hospital to a CT or MRI scanner, need to disinfect the CT or MRI room, and use of iodinated contrast, CT radiation, and long MRI scan times [6].

Use of radiation diagnostic methods for LA and LAA thrombus imaging. TEE is impossible in a pool of patients with gastrointestinal pathologies, primarily due to swallowing problems. In this case, MRI and CT of the heart represent a rational alternative when diagnosing LAA thrombi [7]. Numerous clinical studies have tried to determine the efficiency of radiological diagnostic methods in detecting LAA/LA thrombi in patients with AF.

In a meta-analysis by Romero et al., the mean sensitivity and specificity of cardiac CT in detecting thrombi were 96% and 92%, respectively. In an additional subanalysis of seven prospective single-center studies in which delayed CT imaging was performed, the sensitivity and specificity increased to 100% and 99%, respectively [8].

Spagnolo et al. sought to develop an optimal cardiac CT protocol for diagnosing LAA thrombus in patients with AF using TEE as a reference. The study included 260 patients referred for radiofrequency ablation for AF. All patients underwent cardiac CT and TEE. The CT protocol included one standard angiographic phase and three delayed data collections 1, 3, and 6 min after contrast administration. Thrombi were defined as persistent defects with a 6-min delay in detection.

The results revealed that TEE showed spontaneous contrast in 52 (20%) patients and thrombus in 10 (4%). In 63 (24%) patients, CT demonstrated early LAA filling defects at the angiographic phase, of which 15 (6%) had a persistent defect after 1 min, 12 (5%) after 3 min, and 10 (4%) after 6 min. All 10 TEE-diagnosed thrombi were correctly identified using delayed CT without any false positives. For all phases, the sensitivity was 100%. Specificity and positive predictive value increased from 79% to 100% after 6 min and from 16% to 100%, respectively.

Thus, in patients with persistent AF referred for ablation procedures, cardiac CT including angiographic phase data collection and, in the case of filling defects, a 6-min delayed phase may help reduce the need for TEE. CT can be used to assess the heart morphology and exclude the presence of thrombi in the LAA [9].

Given its high efficacy in detecting LA/LAA thrombi, good visualization of the LAA anatomy, and noninvasiveness of the procedure, CT is a reasonable alternative to TEE when the main aim is ruling out LA and LAA thrombus and in patients whose TEE-associated risk outweighs the benefits [10].

Chun et al. revealed that quantitative radiological signs on cardiac CT help differentiate LAA thrombi from circulatory stasis in patients with valvular heart diseases [11]. Guha et al. established that venogram contrast-enhanced CT with delayed imaging is very specific in ruling out LAA thrombi [12].

A decrease in blood flow velocity in the LAA is associated with a high risk of thromboembolic complications. Ouchi et al. assessed predictors of reduced LAA blood flow velocity on cardiac CT scans in 440 patients with AF. Increased LAA volume, early LAA filling defects on cardiac CT, and higher CHA2DS2[1] scores were independent predictors of decreased LAA ejection fraction in patients with AF. The morphological types of the LAA and AF were not significant predictors of a decrease in blood flow velocity in the LAA. Thus, CT-derived

[1] CHA2DS2/CHA2DS2-VASc is a risk score for stroke and systemic thromboembolism in patients with atrial fibrillation. The abbreviation is formed from the first letters of English words: C, cardiac failure; H, history of arterial hypertension; A, age of ≥75 years; D, diabetes mellitus; S, history of stroke or transient ischemic attack; V, vascular diseases; A, age of 65–74 years; S, sex (female).

parameters may provide additional information for risk stratification and management of thromboembolic complications in patients with AF [13].

Multislice CT can be also used to detect an LAA thrombus. Zhai et al. showed that the absence of a filling defect in the late phase of multispiral CT enables ruling out an LAA thrombus and avoids TEE before catheter ablation in patients with AF at low risk of stroke (CHA2DS2-VASc score ≤ 3) [14].

Cardiac MRI has been evaluated for the diagnosis of LAA thrombus, and some investigators conclude that MRI shows characteristics comparable with TEE in identifying LAA thrombi [15, 16]. The advantages of cardiac MRI over CT include the absence of iodine-containing contrast and radiation exposure. However, CT provides significantly higher spatial resolution, albeit lower temporal and contrast resolution, than cardiac MRI. CT and MRI of the heart are prone to motion artifacts, which are often registered in patients with arrhythmia and difficulty holding their breath [7, 15].

In addition, no significant difference in sensitivity and specificity was found between cardiac CT and MRI. Thus, both methods can be considered reasonable alternatives to TEE for identifying LAA thrombi. Cardiac MRI may be useful when TEE and CT cannot be performed [17].

According to Kitkungvan et al., in patients referred for pulmonary vein isolation, MRI may be the only complete diagnostic study to assess the anatomy of the pulmonary veins and the presence of LA/LAA thrombi, which reduces the number of preoperative tests before the isolation procedure [18].

Radiation methods allow the assessment of patients in the prone position. A study confirmed the accuracy of late-phase contrast-enhanced CT in the prone position for detecting thrombus in patients with persistent or long-standing AF [19]. A contrast-enhanced CT scan in the prone position appears theoretically reasonable, not only for patients who cannot lie on their backs but also from a technical standpoint. After all, the LAA is located in front of the LA, and the contrast agent is heavier than blood; thus, CT in the prone position can be a simple and useful method to avoid false-positive results in relation to the thrombus of these structures [20].

Use of radiation diagnostic methods in LAA occlusion. CT is comparable to TEE for thrombus exclusion but is superior in determining the LAA complex anatomy, measuring the size of the occlusive device, and evaluating pulmonary veins and extracardiac structures [21].

Compared with the transesophageal echo signal, CT before LAA occlusion can provide a more accurate selection of the occlusive device, which creates conditions for more successful device implantation and shorter overall procedure time. CT can also reveal small lobes and trabeculae that may not be visible on TEE [22–24].

A prospective study of patients who were assessed for a new algorithm for calculating the required size of the WATCHMAN occlusive device revealed its results based on the measurement of the LAA ostium area using cardiac CT between March 2017 and October 2019 at the Cleveland Medical Center at University Hospitals. CT measurement of this index predicted accurately the final size of the WATCHMAN occlusive device in 95.6% of cases. This had a potential advantage in the cost of the surgery because the algorithm allowed reducing the average value of used devices per patient [25].

According to Prosper et al. [26] and Toy et al. [27], CT angiography may be a useful adjunct to TEE for the preliminary assessment of the LAA size and identification of anatomical obstructions or contraindications to the deployment of an occlusive device.

According to several studies, CT angiography also serves as a reasonable alternative to TEE and has some advantages over it. These include providing additional information about the LAA depth, which can be valuable in patients who do not have sufficient depth for placement of an occlusive device, as measured by TEE. CT angiography has a higher sensitivity in assessing the residual flow and is also noninvasive [10, 28–30].

CT data can also be used to make 3D LAA models. Hell et al. concluded that 3D-printed LAA models based on preprocedural CT data can help in device selection for a certain patient and predict device compression in the context of LAA occlusion. In this study, the estimated device size based on 3D modeling matched the final size of the implanted device in 21 (95%) of 22 patients. The implantation was successful in all patients. TEE would reduce the device size in 10 (45%) of 22 patients. The device compression determined in the 3D model corresponded to the compression during implantation [31]. Other authors obtained similar data [32].

To solve the problem of the underestimation of the three-dimensional structure of the LAA and the surrounding tissue in fluoroscopy and TEE, China has developed an auxiliary surgical system for LAA occlusion based on preoperative CT images of the heart. It is expected to offer precise guidance for LAA occlusion, increase the success rate and safety of surgery, and aid in surgical training, promoting the spread of the occlusion procedure [33].

Chow et al. demonstrated that the choice of the size of the LAA occlusion device based on preoperative multislice CT is more accurate than the traditional one based on TEE data [34].

The meta-analysis by Sattar et al. revealed that when compared with TEE, CT revealed an increase in the size of the LAA ostium, increase in the probability of predicting the correct size of the device, and reduction in fluoroscopy time in patients undergoing LAA occlusion using the WATCHMAN device. No significant differences were found in other procedural outcomes [35].

Based on the results of current studies, a panel of experts issued recommendations for cardiac CT angiography before placement of a percutaneous LAA occlusion device, which was further endorsed by the French Society for Cardiology and Vascular Diagnostics and Interventional Imaging [36].

Korsholm et al. analyzed cardiac CT and TEE data to evaluate the residual flow during the installation of the LAA occlusive device and its clinical significance. Residual flow assessment is an integral part of follow-up after LAA occlusion. Comparative studies of TEE and cardiac CT are limited, and the clinical relevance of residual flow is unclear.

Korsholm et al. conducted a single-center observational study in patients following LAA occlusion with Amplatzer devices. The analysis included 346 patients with 8-week CT and TEE. According to TEE data, residual flow was present in 110 (32%) patients; in 29 (8%) patients, its diameter was >3 mm. On cardiac CT, 210 (61%) patients had residual flow around the device. Grade 3 residual flow was registered in 63 (18%) patients. Data analysis showed discrepancies between CT and TEE findings in determining the residual flow diameter. Its frequency is significantly higher based on CT data than on TEE data, which indicates a higher information content of CT in this matter [37]. Cardiac CT is superior to TEE in evaluating residual flow and diagnosing other complications of LAA occlusion, such as incomplete ostium closure, occlusal leakage, device thrombosis, and displacement [21].

According to Zhao et al., CT angiography can be used to assess endothelialization of the occlusive device [38].

Over the past 5–10 years, nearly no available studies have evaluated the role of cardiac MRI in LAA closure. According to Guglielmo et al., this is probably a consequence of the higher spatial resolution, scanning speed, and wide CT availability. However, authors believe that cardiac MRI can provide a detailed assessment of LAA [39].

Epicardial space access is an important aspect in many cardiac interventions, including LAA occlusion and AF ablation. Safe access is a serious task that requires deep knowledge of the anatomy of the heart and training and experience of the operator. Studies have reported that MRI-guided epicardial access can be useful and can limit unintentional tissue damage. More importantly, MRI provides continuous visualization of the needle and target throughout the procedure [40].

Use of radiation diagnostic methods for the visualization of thrombosis of an implanted device. CT is a more convenient method for evaluating postoperative complications of LAA occlusion, such as incomplete closure, residual flow, device-associated thrombus, and device displacement [21]. Korsholm et al. analyzed 301 patients and revealed that cardiac CT was as good as TEE (as a reference in this situation) for detecting device-related thrombosis [21, 41].

Use of radiation diagnostic methods in ablation. The measurement of the pulmonary vein diameter can be of great importance when planning a cryoablation procedure. It is best performed using 3D imaging techniques such as CT or MRI of the heart. During ablation, various imaging methods are used for various stages of the surgery to increase the efficiency and safety of the procedure, including reducing radiation exposure. For example, TEE is used to rule out LAA thrombus before surgery, intracardiac echocardiography improves the safety of transseptal puncture and contact with catheter tissue during surgery, MRI and CT help integrate the chamber and pulmonary vein anatomy into the procedural electroanatomical map, and only CT can be used to rule out atrioesophageal fistulas following ablation if the corresponding symptoms appear [7].

According to Vaishnav et al., a system for assessing the anatomy of the LA and pulmonary veins using CT is useful in identifying “unfavorable” anatomy, potentially causing procedural difficulties and poor cryoablation outcomes [42]. However, another study demonstrated that preoperative CT does not improve the safety and efficacy of pulmonary vein ostia ablation by increasing significantly cumulative radiological exposure. In the study, 493 patients with AF underwent preoperative CT before AF ablation. No differences were found in the mean procedure duration and fluoroscopy time between the groups. The cumulative radiation dose was significantly higher in the CT group than in the non-CT group. After 1 year, the absence of AF/atrial tachycardia was comparable between the groups [43].

CT is also used for ablation by ethanol infusion into Marshall’s vein [44]. In patients with persistent AF, who were referred for ablation procedures, cardiac CT including an angiographic phase may help reduce the need for TEE [9].

Advances in cardiac MRI and imaging have made it an excellent tool for assessing atrial myopathy. LA remodeling is the basis for AF development and progression. Using images with or without contrast enhancement, MRI can detect atrial phase volumes, atrial function, and atrial fibrosis. These capabilities make MRI a versatile and unusual tool in the management of patients with AF, including risk stratification, ablation prognosis and planning, and stroke risk assessment [45].

Cardiac MRI with late gadolinium enhancement allows the assessment of atrial fibrotic changes. Studies have used this method to assess the association of an MRI presentation with chronic AF [46], quantify LA fibrosis after AF ablation, and assess the risk of arrhythmia recurrence [47].

A meta-analysis of 24 studies that report the use of cardiac MRI in catheter ablation of pulmonary vein ostia obtained similar data. According to studies of the predictive value of cardiac MRI before ablation, AF fibrosis, quantified by MRI, is associated with the risk of AF recurrence following AF ablation [48].

Use of radiological methods in diagnostics of coronary heart disease in patients with AF. Separately, a study emphasized the possibilities of CT for assessing coronary calcification and diagnosing ischemic heart disease (IHD) in patients with AF, which further influenced patient management and prognosis. In the study by Wang et al., 2238 (62.1%) of 3604 patients with AF had coronary artery calcification on CT. It was independently associated with all predefined endpoints. With adjustment for CHA2DS2-VASc score, coronary calcification was associated with stroke and death from cardiovascular events. After ruling out coronary calcification as a parameter of vascular disease in the CHA2DS2-VASc scale, the decision on the use of anticoagulant therapy was revised in 20.1% of the patients, as well as in 13.5% of patients for whom anticoagulant therapy was indicated [49].

A 5-year retrospective analysis was conducted to evaluate the presence of IHD in 566 patients with paroxysmal or newly diagnosed AF who underwent CT angiography. Accordingly, in patients with paroxysmal or newly diagnosed AF, CT angiography revealed IHD (coronary artery stenosis $\geq$ 50%) in 39.2% of cases. The authors recommended integrating calcification assessment by CT and CT angiography into the diagnostic evaluation of patients with new-onset or paroxysmal AF [50].

Nous et al. analyzed data from 94 patients with AF without confirmed or suspected IHD. They assessed retrospectively the rate of coronary artery calcification and prevalence of obstructive IHD using CT angiography, compared clinical management and 5-year outcomes in patients with and without obstructive IHD, and examined the potential effect of coronary calcification and obstructive IHD as a manifestation of vascular disease on a CHA2DS2-VASc scale. They observed a high prevalence of obstructive IHD according to CT angiography in patients with AF without confirmed or suspected IHD. Patients with AF and obstructive IHD received different treatments and had a worse prognosis than patients without obstructive IHD. Cardiac CT may improve cardiovascular risk stratification in patients with AF [51].

The shortcomings of the presented research methods in patients with AF must be revealed. Although highly effective, cardiac CT exposes patients to increased radiation doses and the potential risk of developing contrast-induced nephropathy. On the contrary, MRI allows for the noninvasive evaluation of cardiac morphology and function without these adverse effects [7].

Conclusion. To date, the management of patients with AF requires the use of various instrumental diagnostic methods to detect thrombi in cardiac cavities. Although TEE is the “gold standard,” it has drawbacks, with invasiveness being the most significant. CT and MRI of the heart have shown high efficiency in detecting LA and LAA thrombi, being noninvasive methods. They are superior to TEE in determining the complex anatomy of the LAA and measuring the size of the occlusive device and some anatomical structures and have additional diagnostic capabilities in patients with AF.

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