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THE ROLE OF MAGNETIC RESONANCE IMAGING AND COMPUTED TOMOGRAPHY IN STUDYING THE MORPHOLOGICAL FEATURES OF THE LEFT ATRIAL APPENDAGE IN THROMBUS FORMATION: A LITERATURE REVIEW

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Abstract

Background. Atrial fibrillation has a marked impact on quality of life, heart failure, risk of thromboembolic stroke and increased mortality from these causes. Understanding the anatomy, arrhythmogenic and thrombogenic components of the left atrial appendage according to magnetic resonance and computed tomography is an important aspect for the choice of specific methods of treatment for many potentially dangerous consequences of this disease.

Aim. The purpose of the study was to analyze sources on the morphological features of the left atrial appendage according to magnetic resonance and computed tomography in thrombus formation.

Search strategy. To analyze and evaluate the morphological features of the left atrial appendage PubMed, Google Scholar, Web of Science and MEDLINE Complete were used before 2022. Scientific articles published more than 10 years ago were included in the work since they contained conceptual information. Studies conducted on patients diagnosed with atrial fibrillation; cross-sectional studies, cohort studies, and case-control studies published in the English language were included in this study. Key terms used for this review include “atrial fibrillation”, “left atrial appendage”, “left atrial size”, “morphology of left atrial appendage”, “computed tomography”, “magnetic resonance tomography” and “left atrial appendage thrombosis”. *Exclusion criteria:* studies conducted with patients diagnosed with atrial fibrillation, evidence-based medicine articles with clear conclusions, articles published in other languages. As a result, 75 articles were selected for this review.

Conclusions. Analysis and further development of risk criteria based on computed tomography and magnetic resonance imaging data are assumed to be effective in the prevention of thromboembolic complications.

Keywords: *left atrial appendage, morphologic features, arrhythmia, cardiogenic thrombosis, review.*

Резюме

РОЛЬ МАГНИТНО-РЕЗОНАНСНОЙ И КОМПЬЮТЕРНОЙ ТОМОГРАФИИ В ИЗУЧЕНИИ МОРФОЛОГЧИЕСКИХ ОСОБЕННОСТЕЙ УШКА ЛЕВОГО ПРЕДСЕРДИЯ В ТРОМБООБРАЗОВАНИИ: ОБЗОР ЛИТЕРАТУРЫ

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Актуальность: Фибрилляция предсердий оказывает заметное влияние на качество жизни, сердечную недостаточность, риск тромбоэмболического инсульта и повышает смертность от этих причин. Понимание анатомии, аритмогенных и тромбогенных компонентов придатка левого предсердия по данным магнитно-резонансной и компьютерной томографии является важным аспектом для выбора специфических методов лечения многих потенциально опасных для здоровья последствий данного заболевания.

Цель: Провести анализ источников по вопросу морфологических особенностей ушка левого предсердия по данным магнитно-резонансной и компьютерной томографии в тромбообразовании.

Стратегия поиска: Для поиска информации по анализу морфологических особенностей ушка левого предсердия были использованы базы данных PubMed, Google Scholar, Web of Science, MEDLINE Complete до 2022 года. Для анализа в работу были включены научные статьи, опубликованные более чем 10 лет назад, так как они содержали концептуальную информацию. *Критерии включения в обзор:* исследования, проведенные с участием пациентов с диагнозом фибрилляция предсердий, опубликованные на английском языке. Ключевые термины: "фибрилляция предсердий", "ушко левого предсердия", "морфология ушка левого предсердия", "размеры левого предсердия", "компьютерная томография", "магнитно-резонансная томография", "тромб ушка левого предсердия". *Критерии исключения:* исследования, проведенные с участием пациентов с диагнозом фибрилляция предсердий, с четкими выводами, статьи, опубликованные на других языках. В результате, для этого обзора было отобрано 75 статей.

Выводы: Анализ и дальнейшая разработка критериев риска на основании данных компьютерной и магнитно-резонансной томографии предполагаются эффективными в профилактике тромбоэмболических осложнений.

Ключевые слова: *ушко левого предсердия, морфологические особенности, аритмия, кардиогенный тромбоз, обзор.*

Түйіндеме

ТРОМБ ТҮЗІЛУДЕГІ СОЛ ЖАҚ ЖҮРЕКШЕ ҚОСАЛҚЫСЫНЫҢ МОРФОЛОГИЯЛЫҚ ЕРЕКШЕЛІКТЕРІН ЗЕРТТЕУДЕГІ МАГНИТТЫҚ-РЕЗОНАНС ЖӘНЕ КОМПЬЮТЕРЛІК ТОМОГРАФИЯНЫҢ РӨЛІ: ӘДЕБИЕТ ШОЛУ

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Өзектілігі. Жүрекшелердің фибрилляциясы өмір сапасына, жүрек жеткіліксіздігіне, тромбоэмболиялық инсульт қаупіне және осы себептерден болатын өлім-жітімнің артуына айтарлықтай әсер етеді. Магниттік резонансты бейнелеу және компьютерлік томография арқылы өлшенетін сол жақ жүрекше қосалқысының анатомиясын, аритмогендік және тромбогендік компоненттерін түсіну осы аурудың денсаулыққа қауіп төндіретін көптеген ықтимал салдарлары үшін арнайы емдеу әдістерін таңдаудың маңызды аспектісі болып табылады.

Мақсаты. Магниттік резонанс және тромб түзілу кезіндегі компьютерлік томографияға сәйкес сол жақ жүрекше қосалқыларының морфологиялық ерекшеліктері бойынша дереккөздерді талдау.

Іздеу стратегиясы. Сол жақ жүрекше қосымшасының морфологиялық ерекшеліктерін талдау туралы ақпаратты іздеу үшін PubMed, Google Scholar, Web of Science, MEDLINE Complete 2022 жылға дейін мәліметтер базасы пайдаланылды. Талдау үшін 10 жылдан астам уақыт бұрын жарияланған ғылыми мақалалар концептуалды ақпараттан тұратындықтан еңбекке енгізілді. *Шолуға қосу критерийлері:* сол журекше фибрилляциясы бар науқастарда жүргізілген зерттеулер, ағылшын тілінде жарияланған. Негізгі терминдер: «жүрекшенің фибрилляциясы», «сол жақ жүрекше қосалқысы», «сол жақ жүрекше қосалқысының морфологиясы», «сол жүрекшенің өлшемдері», «компьютерлік томография», «магниттік-резонанстық томография», «сол жақ жүрекше қосалқысының тромбы». *Алып тастау критерийлері:* жүрекшелердің фибрилляциясы диагнозы бар науқастарда жүргізілген зерттеулер, нақты қорытындылары бар, басқа тілдерде жарияланған мақалалар. Нәтижесінде осы шолуға 75 мақала таңдалды.

Қорытынды. Тромбоэмболиялық асқынулардың алдын алуда компьютерлік томография және магнитті-резонанстық томография деректеріне негізделген тәуекел критерийлерін талдау және одан әрі дамыту тиімді деп болжанады.

Түйінді сөздер: *сол жақ жүрекше қосалқысы, морфологиялық белгілері, аритмия, кардиогенді тромбоз, шолу.*

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Introduction

Atrial fibrillation (AF) is the most common form of cardiac arrhythmias and is one of the causes of the increasing disability and mortality among populations [18, 72,11,65,46]. Cardiac arrhythmias result in sudden cardiac death, which is estimated as a cause of 15%–20% of all deaths [24]. According to the European Society of Cardiology, more than 6 million Europeans currently suffer from AF. The incidence of AF is predicted to increase as the population ages. It is believed that in the next 50 years, the prevalence of this disease will double. Half of the strokes caused by AF occur before the age of 75 [13]. According to the information, the prevalence of AF was 20.9 and 12.6 million worldwide for men and women, respectively, in 2010. It has been proven that every fourth inhabitant of Europe and the United States has a high risk of AF in middle age [31]. AF accounts for 60% of all cardioembolic strokes [9,5]. Cardioembolic sources, mainly represented by thrombi in the left atrial appendage (LAA), are the most common sources of cardioembolic events [2,22, 67].

AF treatment is a real challenge for cardiologists and electrophysiologists. It has a significant effect on patients' quality of life, heart failure, and risk of thromboembolic stroke and increases mortality from the aforementioned causes [10,37,47,67,73]. Understanding the anatomy as well as the arrhythmogenic and thrombogenic components of the LAA is important for the development of specific treatments for AF [38]. The percentage of strokes associated with AF significantly increases from 1.5% at the age of 50–59 years to 23.5% at the age of 80–89 years [7]. Furthermore, the prevalence of AF and the associated risk of thromboembolic events may be significantly underestimated because AF is often asymptomatic and undiagnosed [71]. This finding is supported by a study in which subclinical atrial tachyarrhythmias without clinical AF frequently occurred in patients with pacemakers and were associated with a significantly increased risk of thromboembolic complications [25].

Left atrial appendage morphology.

LAA has a complex anatomical structure different from that of the left atrium (LA). It has different embryological, anatomical, and pathophysiological characteristics. It is characterized by a blindly ending formation of an elongated shape with constrictions and a narrow mouth, which connects with the atrium. This appendage originates from the left wall of the primary LA, which is formed mainly by the adsorption of primary pulmonary veins and their branches. Furthermore, it forms in the fourth week of embryonic development. LAA is located in the atrioventricular sulcus, close to the left circumflex artery, left phrenic nerve, and left pulmonary veins. The junction with the LA is quite well-defined due to the narrowing at the opening of the appendix. There are significant differences in its size, shape, and relationship with adjacent cardiac and extracardiac structures, which can be of great importance in the implementation of interventional procedures [18].

Veinot J.P. et al. reviewed more than 500 cases and found that in more than two-thirds of the cases, LAA consisted of two or more lobes located in different planes. Usually, the lobes of the LAA are directed to the atrioventricular sulcus and basal surface of the left ventricle. This must be borne in mind during imaging studies to exclude an intracavitary thrombus: the inability to view all lobes or incomplete visualization of the lobe may be the reason for insufficient diagnosis of LAA thrombosis [65].

A recent computed tomography (CT) study classified LAA morphology based on the presence of curvature, which exhibits a "chicken wing-like" appearance (48%) or "cactus" shape (30%) with a dominant central lobe and secondary lobes extending from the central lobe in both the upper and lower directions; "windsock" shape (19%) with one dominant lobe; and "cauliflower" shape (3%) with limited overall length and complex internal characteristics [19]. Figure 1 presents the morphological forms of LAA (A - "chicken wing" shape; B - "windsock"; C - "cauliflower" shape; D - "cactus" shape).

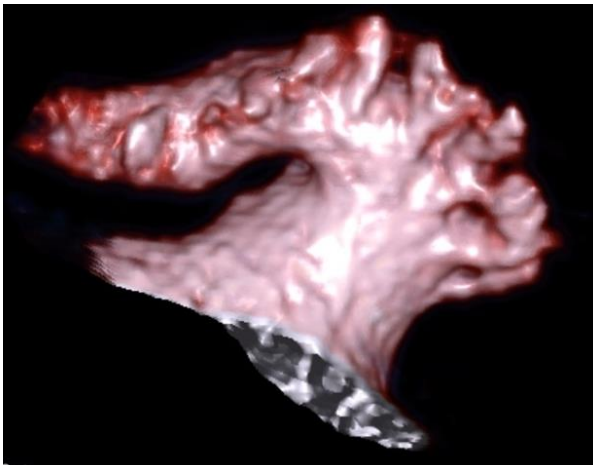

Figure 1 A. «Chicken wing» shape.

Histologically, LAA has a single endothelial layer and contains muscles of varying thickness [61]. The anterolateral wall adjacent to the mitral valve has a minimum thickness of 0.5 mm; therefore, special care must be taken to avoid perforation when performing invasive procedures [59].

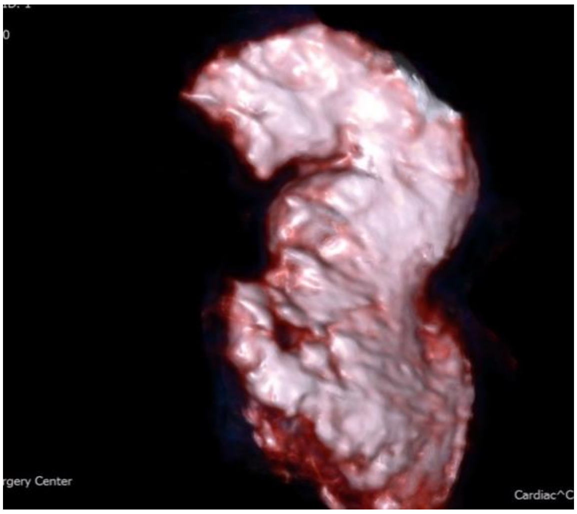

Figure 1 B. «Windsock» shape.

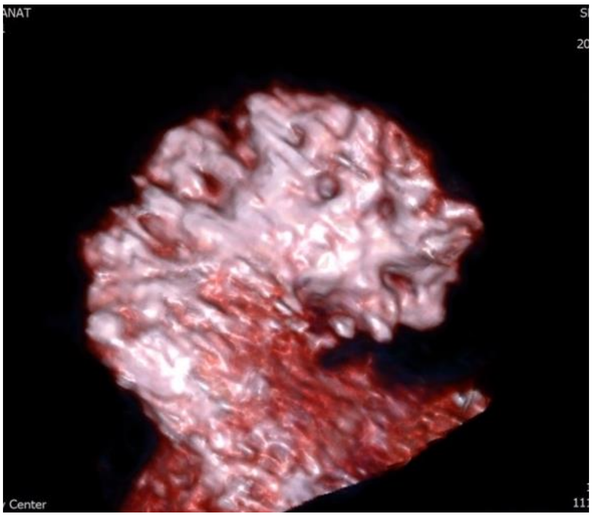

Figure 1 C. «Cauliflower» shape.

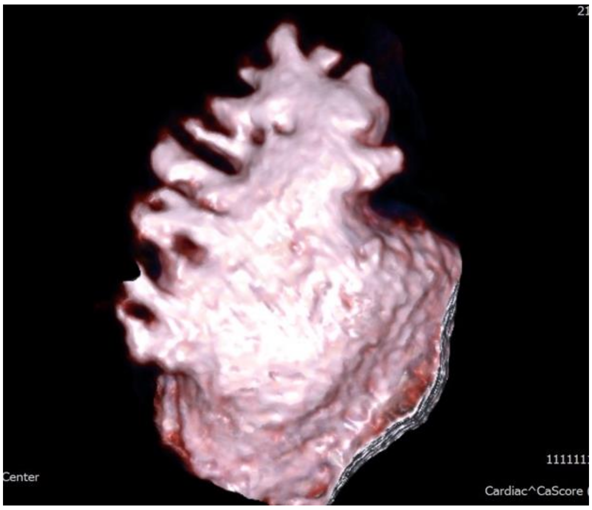

Figure 1 D. «Cactus» shape.

Recently, the risk of stroke in patients with AF has been assessed using the CHA2DS2-VASc score. At least one point is given for each of the following conditions: history of hypertension, diabetes, congestive heart failure, cardiovascular disease, stroke or transient ischemic attack, or female gender. The CHA2 DS2-VASc scale is widely used in clinical practice to initiate anticoagulant therapy. It mainly focuses on well-known risk factors for ischemic stroke, and none of these factors assess LAA, where most of the thrombi in AF are formed. Only in the mid-1950s was LAA, previously considered a trivial and nonfunctional anatomical structure of the heart, identified as the main site of thrombus formation in AF. Numerous studies have demonstrated that 91% to 100% of all blood clots in nonvalvular AF are formed in the LAA [41,63].

The LAA is a remnant of the primary embryonic LA, which explains its trabecular appearance. It is a long-angle structure that differs markedly in shape and size (volume, length, width, and size of the hole) on TEE and magnetic resonance imaging (MRI) of the heart [20,26].

Veinot J.P. et al. (1997) demonstrated that LAA consists of two lobes in half of the population and three lobes in one-third of the people. Although the LAA has a very thin wall, the orifice has a significant myocardial thickness. *Panikker S.* et al. demonstrated on a cadaveric heart that the anterior (2.5 ± 0.8 mm; range 1.4–4.0 mm) and superior (2.4 ± 1.2 mm; range 1.1–4.8 mm) edges of the LAA orifice have the thickest part of the wall diameter [54].

In 2011, *Beinart R. et al.* attempted to correlate the anatomical parameters of the LAA, including LAA volume, depth, the short and long axes of the LAA neck, and the number of lobes. They used MRI as an additional tool to stratify thromboembolic risk in patients with AF. LAA neck dimensions (short and long axes) were the only independent predictor of stroke ($p < 0.001$). Doctors should be careful when using LAA dimensions, including short and long axes and volumes, as predictors of thrombus formation because they may significantly fluctuate over time as a result of LAA remodeling [6].

The morphology of LAA is extremely complex and heterogeneous, and unlike the size of the LAA, it does not change over time in patients with AF. In 2010, a new morphological classification of LAA was proposed, which was based mainly on the presence or absence of “bending” [70]. As aforementioned, there are four morphological types of LAA: “chicken wing,” “cactus,” “windsock,” and “cauliflower.”

In 2012, *Luigi Di Biase et al.* conducted a large multicenter study to correlate the morphological characteristics of LAA obtained *via* CT or MRI with an assessment of the risks of preexisting thromboembolic complications in patients with AF. This study demonstrated that patients with “chicken wing” LAA morphology had a statistically significantly lower risk of stroke than patients with all other described LAA morphologies. More importantly, this study demonstrated that the morphology of LAA in the other three forms (“non-chicken wing”) increased the risk of thromboembolic complications by a factor of 6 compared with the morphology of the “chicken wing” (95% confidence interval (CI): 1.25–79.7, $P = 0.019$) in patients with a CHADS2 score of 0 to 1 [19]. A CHADS2 scale is a clinical tool for predicting and assessing the risk of ischemic stroke in patients with non-rheumatic AF, which is a common and serious heart rhythm disorder associated with cardioembolic stroke.

The same concept was subsequently proven in AF patients with asymptomatic LAA thrombi [3]. Although several studies have reaffirmed results indicating that the LAA plays an important role in predicting thromboembolic complications in patients with AF [39, 36, 56], other studies have reported that LAA morphology is not associated with the risk of stroke in a population with AF [21,32,35,52].

Kimura T. et al. [32] also investigated the association between the morphology of LAA and the risk of stroke. In this study, 26.7% of patients with thromboembolic complications had a CHA2DS2-VASc score of 0. The "cauliflower" morphology of LAA was significantly predominant in these patients. It was demonstrated that this morphology, defined as a main lobe < 4 cm long without split lobes, was significantly more common in patients with thromboembolic complications (odds ratio (OR) = 3.9; P = 0.005) [32]. Logistic regression analysis of CHA2DS2-VASc revealed that "cauliflower" LAA was an independent predictor of stroke (OR 3.3; P = 0.017). In "low-risk" patients, the presence of LAA morphology other than "chicken wing" dramatically increases the risk of thromboembolism, which may indicate the need for oral anticoagulant therapy. *Khurram I.M. et al.* [35] investigated the relationship between the morphology and characteristics of LAA, including trabecular length, orifice diameter, and length, with the prevalence of thromboembolic complications in patients with AF. The LAA morphology did not exhibit statistical significance in predicting embolic stroke. However, multivariate analysis revealed that significant trabecularity of the LAA is an independent risk factor for the development of thromboembolic complications (27.7% versus 14.4%; P = 0.019) [35].

A recent meta-analysis assessed the clinical significance of LAA morphology as a predictor of thromboembolic complications in patients with low to moderate risk of stroke. This study included a total of eight studies involving 2596 patients with AF (84% of the patients had a CHADS2 score < 2). The risk of stroke was 54% lower in patients with "chicken wing" LAA morphology than in those with "non-chicken wing" morphology (OR = 0.46; 95% CI: 0.36–0.58). Similarly, the chicken wing morphology had a lower risk of thromboembolic complications than other morphological types of LAA ("chicken wing" vs. "cauliflower": OR = 0.38; 95% CI: 0.26–0.56; "chicken wing" vs. "windsock": OR = 0.48; 95% CI: 0.31–0.73; "chicken wing" vs. "cactus": OR = 0.49; 95% CI: 0.36–0.66) [42].

Diagnosis of thrombosis of the left atrial appendage.

The gold standard for diagnosing LAA thrombosis is TEE. TEE is a method of ultrasound diagnostics of the heart using a special sensor inserted through the esophagus. This method improves the "ultrasound window" and permits a much clearer visualization of the heart's structures using a transesophageal approach. One of the first to perform TEE was Side in 1971. After 5 years, *Frazin L. et al.* reported M-mode on TEE. They created an oval transducer device that was inserted into the esophagus of 38 awake patients with chronic obstructive pulmonary disease and used transthoracic echocardiography to evaluate the aortic wall and left atrium. In the 1980s, the evaluation of hemodynamics in patients undergoing invasive procedures drove the development of non-invasive color Doppler sonography [62].

In recent years, the technique of three-dimensional TEE, which is of interest primarily in cardiac surgery, has been increasingly introduced into clinical practice. It is used in all cases when the resolution of transthoracic echocardiography does not allow making an accurate diagnosis, studying in detail the anatomy of various intracardiac structures, and assessing intracardiac hemodynamics. Compared to 2D echo, 3D imaging can improve diagnosis and provide a more complete assessment of complex morphologies, particularly in identifying sources of cardiogenic thrombosis [29]. The use of contrast agents improves visualization by eliminating artifacts, obscuring the LAA, and revealing filling defects [69]. TEE also allows functional assessment of LAA flow using the Doppler method [55]. In particular, recent studies have shown that the data of blood cell tracking techniques, which can be quantitatively and qualitatively assessed, provide information on tissue deformation and movement that can correlate with the risk of LAA thrombosis [4]. TEE can identify other predictors of thromboembolism, such as "unstable" plaques on the aorta, echo-spontaneous contrast effect, and decreased blood flow in the LAA.

A decrease in blood flow velocity and LAA contractility are independent factors of thromboembolic complications [75]. Compared with intraoperative data, the sensitivity and specificity of TEE in the diagnosis of LAA thrombosis in patients with AF are 92% and 98%, respectively, with a negative and positive predictive value of 100% and 86% [1, 45].

However, this method is semi-invasive and cannot be performed in some patients due to intolerance to this procedure and several other contraindications, such as malignant neoplasms, esophageal diverticulum, fistulas, strictures, esophageal varices, inflammatory diseases of the esophagus, bleeding from the upper part of the gastrointestinal tract [17, 27, 57,40]. In addition, the procedure requires skilled physicians and support staff, is time-consuming, may cause patient distress, and is expensive. TEE also cannot provide complete information about the anatomy of the pulmonary veins before performing pulmonary vein isolation, which is another disadvantage of this type of study.

A prerequisite for this procedure is a 4-6 hour fast before the study, removable dentures must be removed before the study.

TEE can be replaced by CT angiocardiography of the left heart, which allows non-invasively and on an outpatient basis to assess the presence and absence of a left atrial appendage thrombus. According to the literature, CT angiography is effective in excluding thrombosis of the heart cavities, but its capabilities have not been fully studied. CT angiography is not inferior to TEE for detecting stasis and thrombosis in the left atrial cavity; however, the technique's efficacy requires further investigation.

The technical development of equipment has developed rapidly with the advent of new generations of tomographs – from the first 4-slice to modern 640-slice tomographs. CT of the latest generation, after technical improvement, is characterized by a decrease in the number of detectors, an increase in the speed of rotation of the X-ray tube, as well as high spatial and temporal resolution, which made it possible to examine the left parts of the heart, not only to exclude thrombosis but also to evaluate coronary blood flow.

The use of synchronization with electrocardiogram in CT eliminates artifacts from heart movements at high heart rates, which made it possible to increase diagnostic accuracy. With the use of multislice CT, the time required to retain one's breath, the dosage of the injected contrast agent, and the patient's radiation exposure have been significantly reduced.

Unlike TEE, the method is non-invasive. However, CT is an absolute contraindication when the patient is allergic to an iodinated contrast agent. There are also relative contraindications: severe diseases of the kidneys and thyroid gland, pregnancy, and high patient weight.

The sensitivity of CT and the negative predictive value of the study is improved by a two-stage scanning technique that includes delayed visualization of the LAA. CT of the heart, especially when delayed scanning of the left atrial appendage is used, is an alternative to TEE for diagnosing left/left atrial thrombi/clots, avoiding the inconvenience and complications of TEE. A non-invasive approach equivalent to TEE for the diagnosis of intracardiac thrombi with high diagnostic accuracy is eligible for clinical use as an alternative and screening method. For cardiac thrombi, CT is a well-established but underutilized imaging modality. CT is highly accurate in detecting intracardiac thrombi [28,33, 64]. A recent meta-analysis showed that the high diagnostic accuracy of cardiac CT compared with TEE can be used to detect left atrial thrombi in patients with AF. The authors included 19 studies involving 2955 patients and determined that the sensitivity and specificity of CT were 96% (95% CI: 92–100%) and 92% (95% CI: 91–93%), respectively, while positive and negative predictive values were 41% (95% CI: 37–44%) and 99% (95% CI: 99–100%), respectively [60]. The results of studies presented by *Romero J. et al.* showed that biphasic delayed scanning significantly improved the specificity and diagnostic accuracy of imaging by up to 91% compared with conventional angiography, which is 41% [60]. This is since a pseudo-filling defect with severe blood stasis can mimic an intracardiac thrombus.

In a recent publication by *Lazoura O. et al.,* cardiac CT performed on 122 patients undergoing surgery for arrhythmias showed 100% predictive value using delayed scanning [43].

Pietro Spagnolo et al. demonstrated an additional delayed LAA scan at 6 minutes in patients with drug-resistant persistent atrial fibrillation, which can be considered as an alternative to TEE [66]. Other studies have demonstrated that an additional delayed scan of the LAA in the prone position of patients enhances the diagnostic accuracy of left atrial appendage thrombosis. CT in the prone position using repeated delayed phase LAA scanning has been illustrated by *Rena Nakamura et al.* [51]. In patients with persistent and long-standing AF before catheter ablation, late-phase CT imaging is an important tool for assessing intracardiac thrombi and LAA dysfunction. However, for some patients, the prone position is not physiological and causes inconvenience.

When scanning in the supine position, the LAA lies in a horizontal plane, and in some cases, a second scan of the LAA is required, which increases the dose of radiation exposure to the patient. In one clinical case of cryoballoon ablation, the left lateral prone position in AF was used, in which the left atrium was compressed by a dilated aorta and vertebrae, the use of a CT scan of the heart lying on the left side showed that the heart could move forward and left atrial compression could be eliminated [50].

The advantages of CT demonstrate the potential of this technology for evaluating the morphological characteristics of the left atrium and the presence or absence of a thrombus in the heart cavities, which will unquestionably improve the risk stratification for developing embolic complications. Due to the insufficiency of work on this topic and the absence of scientific advancements in our country, it is necessary to conduct additional research on this issue, taking into consideration comorbidities, which will help in the future to assess and predict the complications of the disease.

MRI can be used to detect left atrial thrombi with or without contrast media. The usefulness of double or triple inversion turbo spin echo sequences for assessing thrombus in LAA was investigated by *Ohyama H. et al.* in 50 patients diagnosed with AF and a history of cardioembolic stroke. MRI was found to have high intra- and inter-observer reproducibility, with high agreement in thrombus detection in the LAA compared to TEE (kappa = 0.876, SE = 0.068). The authors also noted that thrombus sizes detected on MRI were consistently ≈20% larger than on TEE [53]. Another early study showed that the diagnostic accuracy of contrast-enhanced MRI for excluding LAA thrombus was low due to insufficient spatial resolution [49, 14]. Compared to TEE, the sensitivity of the 2D steady-state free precession sequence with saturation-recovery and 3D low-angle turbo-fast imaging for LAA thrombus detection was 47% and 35%, respectively, and the specificity was 50% and 67%, respectively. Both 2D and 3D methods overestimated the size of the thrombus compared to TEE measurements by 66% and 25%, respectively.

With recent advances in sequence development and the capabilities of paramagnetic contrast agents, an increasing number of studies have demonstrated that MRI's diagnostic accuracy has improved. *Rathi V.K.* [58] compared the effectiveness of 2D non-contrast cine images, contrast-enhanced 2D/3D sequences, and TEE data in diagnosing LAA thrombosis in 97 patients diagnosed with AF. Both 2D and 3D contrast-enhanced MRI detected LAA thrombi in 2 of 97 patients with 100% agreement with TEE, while 2D cine-MRI was indeterminate in 6 patients. *Kitkungvan D.et al.* [34] used TEE as a reference standard to study the diagnostic performance of various MRI techniques in detecting LAA thrombus in 261 patients followed by pulmonary vein mapping. Using TEE, LAA thrombus was diagnosed in 9 patients. Delayed enhancement MRI with inversion time (DE-CMR) had the highest diagnostic accuracy (99.2%), sensitivity (100%), and specificity (99.2%), followed by magnetic resonance angiography (MRA) with contrast (accuracy, 94.3%, sensitivity 66.7% and specificity 95.2%) and cine mode (accuracy 91.6%, sensitivity 66.7% and specificity 92.5%) with an excellent correlation between observers on all three methods.

DE-CMR has the highest sensitivity, specificity, and predictive diagnostic performance among other MR sequences.

Recent improvements in MRI as a new non-invasive method of cardiac imaging tool allow to study of the morphological and functional features of the heart without sedation, radiation, or nephrotoxicity. Cine mode can evaluate the phase functions of the right and left parts of the heart. A study with a contrast agent is excellent for assessing the number, size, and shape of the pulmonary veins. Moreover, it accurately characterizes the highly variable anatomy of the pulmonary veins and identifies pulmonary vein stenosis as one of the common complications after radiofrequency catheter ablation [23, 30,48]. DE-CMR can evaluate LA fibrosis, with the degree of delayed enhancement significantly correlated with procedural outcomes [8,12,44]. Obtaining three-dimensional anatomy of the LA and pulmonary veins before ablation improves safety, reduces the radiation dose, and increases the accuracy of the procedure.

The main advantage of MRI over echocardiography and CT is its ability to characterize tissue, including tissue and thrombus differentiation, and identification of myocardial tissue scarring using delayed enhancement imaging. Several studies have shown the possibility of using DE-CMR to localize and quantify LA fibrosis, which is associated with an increased risk of cerebrocardiovascular disease and is a useful indicator of AF severity and prognosis [15, 16].

Conclusion. The morphology of the LAA may be a significant parameter in the prediction of thrombosis and may have an impact on the stratification and anticoagulation therapy of individuals with low to moderate risk of thromboembolism. The investigation of the anatomical characteristics of the LA remains pertinent because additional stratification of thrombus formation hazards is still required. The morphological characteristics and diagnosis of left atrial appendage thrombosis can be studied using a variety of techniques.

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