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RESEARCH

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Morphology and location of thrombus and sludge in patients with non-valvular atrial fibrillation

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Abstract

Background Stroke and thromboembolism in nonvalvular atrial fibrillation (NVAF) primarily arise from thrombi or sludge in the left atrial appendage (LAA). Comprehensive insight into the characteristics of these formations is essential for effective risk assessment and management.

Methods We conducted a single-center retrospective observational of 176 consecutive NVAF patients with confirmed atrial/appendage thrombus or sludge determined by a pre-ablation transesophageal echocardiogram (TEE) from December 2017 to April 2019. We obtained clinical and echocardiographic characteristics, including left atrial appendage emptying velocity (LAAeV) and filling velocity (LAAfV). Data analysis focused on identifying the morphology and location of thrombus or sludge. Patients were divided into the solid thrombus and sludge groups, and the correlation between clinical and echocardiographic variables and thrombotic status was analyzed.

Results Morphological classification: In total, thrombi were identified in 78 patients, including 71 (40.3%) mass and 7 (4.0%) lamellar, while sludge was noted in 98 (55.7%). Location classification: 92.3% (72/78) of patients had thrombus confined to the LAA; 3.8% (3/78) had both LA and LAA involvement; 2.7% (2/78) had LA, LAA and RAA extended into the RA, the remained 1.2%(1/78) was isolated to RAA. 98.0% (96/98) of patients had sludge confined to the LAA; the remaining 2.0% (2/98) were present in the atrial septal aneurysm, which protrusion of interatrial septum into the RA. The thrombus and sludge groups showed low LAAeV (19.43 ± 9.59 cm/s) or LAAfV (17.40 ± 10.09 cm/s). Only LA dimension ≥ 40 mm was independently associated with the thrombus state in the multivariable model.

Conclusion This cohort study identified rare thrombus morphology and systematically summarized the classification of thrombus morphology. The distribution of thrombus and sludge outside limited to LAA was updated, including bilateral atrial and appendage involvement and rare atrial septal aneurysm sludge. LAAeV and LAAfV were of limited value in distinguishing solid thrombus from sludge.

Clinical Trial Number ChiCTR-OCH-13,003,729.

Keywords Thrombus, Sludge, Morphology, Location, Atrial fibrillation, Transesophageal echocardiography

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Background

In nonvalvular atrial fibrillation (NVAF), stroke and thromboembolism primarily originate from thrombus or sludge in the left atrial appendage (LAA) [1, 2]. Compared to a 1.6% annual mortality in patients without LAA thrombi or sludge, the risk was 23% in patients with these conditions [1]. The prevalence of LAA thrombus is 3.2–21%, and sludge is 7–18% [1–3]. In comparison, the prevalence of LA thrombus in at least three weeks of anticoagulated patients with AF/atrial flutter is ~3% [4]. In contrast to thrombi that were localized to or were present in the LAA and extended into the left atrial (LA) cavity in 57% of patients with rheumatic AF, 91% of nonrheumatic AF-related thrombi were isolated to or originated in the LAA.

However, the data was based on observational studies from the 1990s [5]. In recent years, although extensive retrospective research has focused on LAA thrombi, the morphology, location, and attachment of extraluminal LAA thrombi, as well as right atrial (RA) and intraluminal right atrial appendage (RAA) thrombus in NVAF, have been rarely studied or detailed [6]. Due to the misdiagnosis of thrombi, some patients had to undergo prolonged anticoagulation and could not be able to receive rhythm-control therapy when necessary. Identifying the characteristics and status of the thrombus and sludge, developing an appropriate antithrombotic treatment strategy, and conducting a TEE review before catheter ablation is important for cardiologists. We retrospectively observed thrombus and sludge using transesophageal echocardiography (TEE) in patients with NVAF.

Methods

We retrospectively screened consecutive patients with AF admitted to the Atrial Fibrillation Center of Beijing An Zhen Hospital who had undergone pre-ablation TEE from December 2017 to April 2019. To be included, patients had to have a confirmed atrial/appendage thrombus or sludge, as determined by TEE. The exclusion criteria included: (1) valvular heart disease, such as rheumatic heart disease, moderate/severe mitral stenosis, and those with prosthetic heart valves; (2) congenital heart disease; (3) ventricular/aortic thrombus; (4) cardiac occupying lesions (e.g., atrial mucinous tumor); (5) post-LAA occlusion or surgical LAA occlusion/exclusion; (6) device-related thrombus (e.g., thrombus on atrial septal closure device); (7) congenital absence of left atrial appendage; (8) thrombus/sludge confirmed by repeat TEE during study period. All clinical data, including information on anticoagulation therapy, were collected. The laboratory result at baseline estimated glomerular filtration rate (eGFR) was estimated based on creatinine measurement at hospital admission before TEE, using the Modification of Diet in Renal Disease (MDRD) Study equation. The study patients were divided into the solid thrombus and sludge groups according to their thrombotic status on TEE. Baseline characteristics are summarized in Table 1.

The study protocol followed the principles of the Declaration of Helsinki and received approval from the Human Ethics Review Committee of Beijing An Zhen Hospital. All patients provided written informed consent for inclusion.

Echocardiography

Initially, all patients underwent transthoracic echocardiography, followed by a multiplane TEE within 48 h before ablation, using a Philips EPIQ7C scanner equipped with a S5-1 (2.5–5.0 MHz) 2D probe, GE VIVID 7.0, or GE VIVID 9.0 ultrasound system. The LA dimension and left ventricular end-diastolic diameter were measured by M-mode echocardiography. Left ventricular ejection fraction was acquired according to the American Society of Echocardiography guidelines [7]. TEE was performed using a 5-MHz multiplane probe, continuous ECG monitoring, and invasive blood pressure measurements. General anesthesia with intravenous injection of propofol (propofol, 1 mg/ml, Fresenius Kabi AB) was preferred for all patients without contraindications. Those who could not tolerate it received pharyngeal anesthesia with 10% lidocaine throat spray. No significant adverse effects occurred during TEE.

First, bilateral atrial and appendage have always been evaluated routinely. LAA was viewed using multiplane imaging by rotating the imaging sector from 0° to 180° during continuous visualization of the appendage to identify the presence or absence of LAA thrombi. Images of the LAA were acquired at 0°, 60°, 90°, and 130° to explore all of its lobes entirely. The RAA was examined in a mid-esophageal section at 90° and 130°, and additional views were used as needed. However, to achieve a complete exploration and differentiate thrombus from stacked pectinate muscles and reverberations, at least two different views were visualized. Second, the LAA velocity profiles included emptying (LAAeV) and filling blood flow velocity (LAAfV) measured at the angle that provided the longest LAA dimension, placing the pulsed Doppler sample volume in the proximal third of the appendage within the orifice of the LAA. LAAeV, late diastolic, positive Doppler outflow signal, shortly following the onset of the ECG P wave. LAAfV is an early systolic, negative Doppler inflow signal immediately following LA contraction. The values of five consecutive cardiac cycle measurements were averaged in patients in sinus or AF rhythm [8]. The same two echocardiogram experts conducted all echocardiographic measurements.

Table 1 Baseline clinical characteristics for thrombus or sludge

Characteristics	Total *n* = 176	Sludge *n* = 98	Thrombus *n* = 78	*p* value
Age (years)	64.50 ± 10.65	66.35 ± 9.35	62.18 ± 11.74	0.010
Female, n (%)	60 (34.1)	30 (30.6)	30 (38.5)	0.275
Body mass index (kg/m^2)	25.86 ± 3.30	25.71 ± 3.53	26.03 ± 3.05	0.582
Nonparoxysmal AF, n (%)	152 (86.4)	82 (83.7)	70 (89.7)	0.244
Hypertrophic cardiomyopathy	18 (10.2)	9 (9.2)	9 (11.5)	0.609
Comorbidities				
Diabetes, n (%)	34 (19.3)	22 (22.4)	12 (15.4)	0.238
Hypertension, n (%)	121 (68.8)	67 (68.4%)	54 (69.2)	0.902
Congestive heart failure, n (%)	42 (23.9)	22 (22.4)	20 (25.6)	0.622
Ischemic stroke, n (%)	39 (22.2)	26 (26.5)	13 (16.7)	0.118
Vascular disease, n (%)	8 (4.5)	3 (3.1)	5 (6.4)	0.289
eGFR < 60mL/min/1.73 m^2, n (%)	21(11.9)	13(13.3)	8(10.8)	0.541
Chronic obstructive pulmonary disease, n (%)	5(2.8)	4(4.1)	1(1.3)	0.267
Obstructive sleep apnea, n (%)	11(6.3)	7(7.1)	4(5.1)	0.583
CHA_2DS_2-VASc	2.70 ± 1.46	2.85 ± 1.50	2.53 ± 1.38	0.146
Anticoagulation use, n (%)	30 (17.0)	18 (18.4)	12 (15.4)	0.390
Echocardiographical characteristics				
LA dimension (mm)	44.40 ± 5.91	43.17 ± 5.2	45.70 ± 6.35	0.011
LVEDd (mm)	49.26 ± 6.97	48.94 ± 6.63	49.58 ± 7.37	0.592
IVS (mm)	11.04 ± 2.37	10.95 ± 2.53	11.13 ± 2.21	0.680
LVEF (%)	57.52 ± 11.59	58.01 ± 11.19	57.01 ± 12.06	0.610
E-wave (cm/s)	91.44 ± 18.54	91.47 ± 19.92	91.58 ± 18.48	0.993
Pulmonary artery pressure	33.04 ± 8.36	32.39 ± 7.19	33.69 ± 9.41	0.343
Mitral regurgitation moderate-to-severe, n (%)	37 (21.0)	17 (17.3)	20 (25.6)	0.180
Tricuspid regurgitation moderate-to-severe, n (%)	51(29.0)	28 (28.6)	23 (29.5)	0.894
SEC, n (%)	175 (99.4)	97 (99.0)	78 (100.0)	0.371
LAA-eV (cm/s)	19.43 ± 9.59	18.10 ± 6.37	21.75 ± 13.27	0.044
LAA-fV (cm/s)	17.40 ± 10.09	16.65 ± 8.06	18.73 ± 12.90	0.278

Data are expressed as number (%) or mean (SD). *Abbreviations* PAF, paroxysmal atrial fibrillation; eGFR, estimated glomerular filtration rate; LA, left atrial; LAA, left atrial appendage; LVEDd, left ventricular end-diastolic diameter; IVS, intraventricular septum thickness; LVEF, left ventricular ejection fraction; LAAeV, left atrial appendage emptying velocity; LAAfV, left atrial appendage filling velocity

Definition

A solid thrombus was defined, based on multiple imaging planes, as a well-circumscribed, solid echo density, acoustically organized mass distinct from the underlying endocardium and pectinate muscles that was less heterogeneous and dynamic than sludge, which was visualized in at least two perpendicular planes during echocardiography. Sludge was defined as an intracavitary echo density with viscid gelatinous qualities, forming precipitates as viewed by multiplane imaging and having a LAAeV < 20 cm/s, but without a discrete organized mass, continuously seen throughout the cardiac cycle. Sludge appears denser and has more layers than severe spontaneous echo contrast (SEC). Severe SEC was recognized as dynamic, swirling, intense echo density and very slow swirling patterns within the LAA cavity with an LAAeV 20–40 cm/s [9, 10] (Fig. 1). The atrial septal aneurysm has confirmed the diagnosis as the protrusion of interatrial septum more than 15 mm into the right or left atrium with an at least 15 mm diameter base of interatrial septum [11].

Statistical analysis

Continuous variables were expressed as the mean ± standard deviation or median with interquartile range. The comparison of proportions was analyzed using Pearson's chi-square test or the Fisher exact test. First, the data obtained before the ablation were examined between the solid thrombus and sludge groups. Second, the following clinical factors potentially related to thrombus from previous studies: age, hypertrophic cardiomyopathy, presence of comorbidities including hypertension, diabetes mellitus, vascular disease, ischemic stroke, eGFR < 60mL/min/1.73 m^2 [12]and LA dimension, left ventricular ejection fraction (LVEF), LAAeV and LAAfV were included in the univariable analysis. The cutoff value for LA dimension, LAAeV and LAAfV in assessing solid thrombus was determined using a receiver operating characteristic (ROC) curve analysis. Univariate and multivariate logistic regression models were used to control for all possible confounding factors and to assess the interaction between variables for assessment of thrombus and sludge. The univariate and multivariate odds ratios (OR) and their corresponding 95% confidence intervals (CI) are given. All statistical tests were two-sided, and $P < 0.05$ was considered to indicate significance. Statistical analyses were performed with SPSS 26.0 software (Chicago, IL, USA).

Results

Population characteristics

Three thousand two hundred fifty-four patients with AF who underwent preoperative TEE were screened, and 222 cases of thrombi or sludge were identified. Excluding

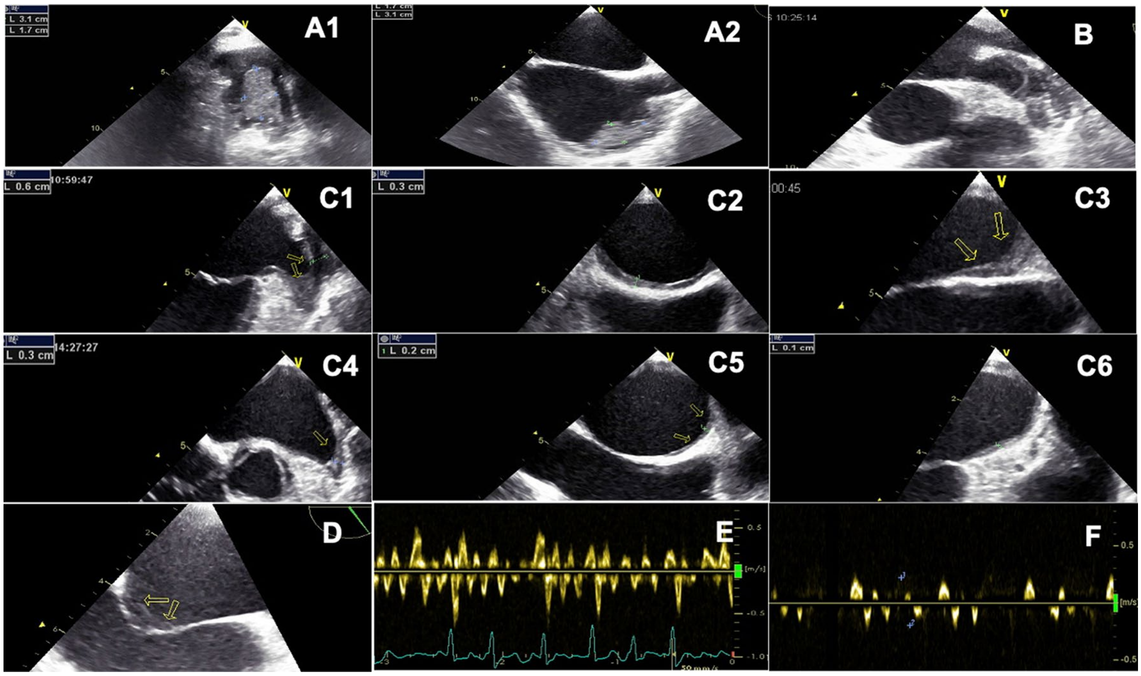

Fig. 1 **(A1, A2)** Thrombus in the LAA and RAA extended into the bilateral atrial in the same patient. **(B)** Sludge is located inside LAA. **(C1, C2, C3)** Before anticoagulation, a solid lamellar thrombus was diffuse and attached to the LA, including the atrial septum and LAA. **(C4, C5, C6)** Thrombus decreased in the same patients who received anticoagulation for eight weeks. **(D)** Sludge in the atrial septal aneurysm is a protrusion of the interatrial septum into the RA. **(E, F)** Pulsed-Doppler tracing of LAA flow in an AF patient without thrombus/sludge; in an AF patient with thrombus/sludge

46 cases: moderate/severe mitral stenosis or mitral mechanical valve replacement in 24 cases, aortic valve mechanical valve replacement in 2 cases, pericardial dissection in 1 case, endocardial cushion defect correction in 1 case, thrombus on atrial septal closure device in 1 case and 17 cases of thrombi/sludge on second TEE review, 176 cases were finally enrolled.

The age of the enrolled patients was 64.50±10.65 years; 65.9% (116/176) were male, 86.4% (152/176) had non-paroxysmal AF, and 22.2% (39/176) had previous stroke/transient ischemic attack. The enrolled patients had a CHA2DS2-VASc score (2.70±1.46), including 6 cases with a score of 0 and 36 cases with a score of 1. 17.0% (30/176) of the patients took warfarin or non-vitamin K antagonists before enrollment. The difference in clinical variables between the solid thrombus group and the sludge group is shown in Table 1.

Echocardiographic characteristics

The LA dimension was 44.40±5.91 mm, and the LVEF was 57.52±11.59%. There were 10.2% (18/176) of patients diagnosed with hypertrophic cardiomyopathy (no obstruction at rest), 1 with dilated cardiomyopathy, 1 with alcoholic cardiomyopathy, and 1 with restrictive cardiomyopathy. 23.9% (42/176) patients were diagnosed with chronic heart failure at enrollment, of whom 42.86% (18/42) had an LVEF of less than 40%. Patients with thrombus had a larger LA dimension. Both thrombus and sludge groups showed low LAAeV (19.43±9.59 cm/s) or LAAfV (17.40±10.09 cm/s). LAAeV in the sludge group was lower than in the group with thrombus (LAAeV: 18.10±6.37 cm/s vs. 21.75±13.27 cm/s, $P=0.044$). The LAAfV did not significantly differ between the two groups. 99.4% (175/176) of patients had SEC.

In total, 94.0% (165/176) of patients underwent TEE under intravenous general anesthesia, and the remaining patients used lidocaine for local anesthesia.

Morphology and location characteristics of thrombus/sludge

Classification of solid thrombus location: 92.3% (72/78) of patients had thrombus confined to the LAA; 3.8% (3/78) had both LA and LAA involvement; 2.7% (2/78) had LA, LAA and RAA extended into the RA, the remained 1.2%(1/78) was isolated to RAA.

Classification of sludge location: 98.0% (96/98) of patients had sludge confined to the LAA; the remaining 2.0% (2/98) were present in the atrial septal aneurysm, which protruded from the interatrial septum into the RA.

Classification of thrombus/sludge morphology: 40.3% (71/176) were mass, 4.0% (7/176) were lamellar, and 55.7% (98/176) were sludgy. Table 2 displays the location distribution of different types of thrombi/sludge (Fig. 1).

Table 2 The location distribution of different types of thrombi/sludge

	Total	LAA	LA + LAA	LA + LAA + RA + RAA	Atrial septal aneurysm	RAA
Massive thrombus	71	68	0	2	0	1
Lamellar thrombus	7	4	3	0	0	0
Sludge	98	96	0	0	2	0

Abbreviations LAA, left atrial appendage; LA, left atrial; RA, right atrial; RAA, right atrial appendage

Table 3 Univariate and multivariate risk factors of thrombus state

	OR (95% CI)	*p* value
Univariate Analysis		
Age	0.962 (0.934, 0.991)	0.012
Hypertrophic cardiomyopathy	1.290 (0.486, 3.423)	0.609
Nonparoxysmal AF	1.707 (0.690, 4.227)	0.248
Congestive heart failure	1.191 (0.594, 2.388)	0.622
Hypertension	1.041 (0.548, 1.979)	0.902
Diabetes	0.628 (0.289, 1.366)	0.241
Ischemic stroke	0.744 (0.513, 1.080)	0.120
Vascular disease	2.169 (0.502, 9.372)	0.300
eGFR < 60mL/min/1.73 m^2	0.747(0.293, 1.905)	0.542
CHA_2DS_2-VASc	0.857 (0.695, 1.056)	0.147
LA dimension ≥ 40 mm	2.738 (1.057, 7.094)	0.038
LVEF (%)	0.999(0.993, 1.005)	0.727
LAAeV ≤ 16 cm/s	0.503 (0.229, 1.106)	0.088
LAAfV ≤ 15 cm/s	0.582(0.274, 1.238)	0.160
Multivariate Analysis		
Age	0.960 (0.919, 1.002)	0.064
LA dimension ≥ 40 mm	5.424 (1.122, 26.221)	0.035
LAAeV ≤ 16 cm/s	0.557 (0.221, 1.401)	0.214

Abbreviations OR, odds ratio; CI, confidence interval; LA, left atrial; LVEF, left ventricular ejection fraction; LAAeV, left atrial appendage emptying velocity; LAAfV, left atrial appendage filling velocity

Association between integrated clinical and echocardiographic variables and thrombotic state

An LAAeV of 16.5 cm/s was set as a cutoff value based on the receiver operating characteristic (ROC) curve analysis with 75.0% sensitivity and 54.2% specificity. An LAAfV of 15.5 cm/s was set as a cutoff value based on the ROC curve analysis with 66.7% sensitivity and 45.8% specificity. An LA dimension of 39.5 cm/s was set as a cutoff value based on the ROC curve analysis with 100.0% sensitivity and 37.5% specificity. Using multivariate analysis, only LA dimension≥40 mm was independently associated with thrombus (Table 3).

Discussion

Major findings

Our study summarized the classification of thrombus/sludge morphology in patients with NVAF, especially the first discovery of lamellar thrombus except for the mass and sludy. For the location of the thrombus in NVAF, the distribution of the thrombus/sludge in the atrial outside the LAA and the rare atrial septal aneurysm was summarized. Finally, an integrated analysis of clinical and echocardiographic variables of solid thrombus and sludge showed that only LA enlargement was independently associated with thrombus state. Our study is the first comprehensive data update on thrombus/sludge morphology and location distribution in patients with NVAF.

Comparison with previous studies

In contrast to sludge, many previous studies of NVAF involving thrombus focused on the incidence of thrombus. With high interstudy heterogeneity, there is a large variation in the rate of positive thrombus by centers [1, 3, 5]. The prevalence of NVAF thrombus ranges between 0.5 and 71.5%, with a resulting weighted mean prevalence of 9.8% [3]. Sludge has recently sparked renewed interest in evaluating the prognosis. However, with different definitions of sludge, reported incidence and prognosis are inconsistent. A few previous studies reported the thrombus location or morphology using cardiac computed tomography or TEE, including valvular AF and NVAF patients. The definition of NVAF was also based on past definitions of NVAF. In addition, the misdiagnosis of thrombus is non-negligible. TEE is the gold standard in detecting LAA thrombus with reported sensitivities of 93–100% and specificities of 99–100% when compared to thrombi detected on cardiotomy procedure, the pulmonary venous ridge and the LAA pectinate muscle are still frequently misdiagnosed [13, 14]. In contrast, our prospective study summarized the thrombus and sludge morphology and location on TEE before ablation for consecutive patients with NVAF, which could avoid selection bias.

Secondly, low LAA flow velocities and SEC are associated with stroke and LAA thrombus formation [10]. While LAAeV has been studied using retrospective research methods by limited studies, LAAfV was rarely involved in these studies.

The possible mechanisms association between laa flow velocities and thrombus/sludge formation

In patients with NVAF, studies have shown that persistent AF, higher CHA2DS2VASc scores, and reduced left ventricular ejection fraction and LA enlargement are associated with LA thrombus formation [15]. In addition to known clinical risk factors, the morphology and function of the LAA itself are also associated with thrombus formation [16, 17]. Firstly, the LAA has an active contractile function, as reflected by changes in blood flow velocity and myocardial trabeculae in the LAA [18]. However, the anatomical morphology of the LAA is highly variable, with 97% of wall commissural muscle > 1 mm and LAA lobes ≥ 3 putting the risk of thrombus formation at increased risk [16, 19]. Secondly, the LAA regulates LA pressure by sensing atrial traction and secreting atrial natriuretic peptide [20]. LAA compliance is high, and as LA increases, early and late LAA emptying velocity decreases, followed by appendage expansion [21]. Blood flow vortices in the enlarged LAA are prone to sludge formation. Thrombus/sludge is associated with LAA emptying flow velocity < 20 cm/s or dense Sects. [10, 22]. In patients with thrombus/sludge with different morphology and location, LAA flow velocities (including LAAeV and LAAfV) are reduced and accompanied by severe SEC. From the hemodynamic point of view, this sludge or dense SEC may be present even with extended anticoagulation therapy until sinus rhythm is restored. In patients with solid thrombus, this phenomenon of decreased flow velocity will present even after the thrombus has dissolved. This may explain why the enlarged LA is more associated with sludge formation than solid thrombus formation. The formation mechanism of thrombus and sludge may not be the same.

Morphology and location of thrombus and sludge

Our observations revealed two thrombus morphologies of NVAF, mass, and laminar. The first was the massive thrombus, an organized solid thrombus, the most described in previous case reports, and accounted for 40.3% of all thrombi in our study. 2/176 thrombi on both sides of the appendage extending into the atria were both diagnosed as hypertrophic cardiomyopathy. This was consistent with an 8-fold higher risk of stroke/thromboembolism in hypertrophic cardiomyopathy patients with AF than patients with NVAF [23]. Second, we found a lamellar thrombus the first time, undetected by TEE, was a solid thrombus, diffuse and attached to the LA, including the atrial septum, before anticoagulation and LAA. After anticoagulant treatment and repeat TEE imaging, the thickness of the echogenic structure was significantly reduced, and the thrombus was further confirmed as not an epicardial fat pad. It was worth noting that although this type of thrombus involves the LA, it was prone to underdiagnosis by TEE because of the more uniform thickness of the involvement of each atrial wall, and the thrombus echo can be identified as different from the normal myocardial echo.

Sludge also may be reported as a prethrombotic state, which is often difficult to differentiate from a thrombus [2, 24]. It seemed to have a similar impact on ischemic stroke and death prevalence at one-year follow-up as does a thrombus [1, 2]. Small studies have also shown no significant thromboembolic events occurred during or after the AF ablation or cardioversion in these patients [25, 26]. However, for patients with documented LAA sludge, it was considered a contraindication to the procedure in current management strategies among centers equivalent to the presence of thrombus [9].

Compared to 11–18% of LAA thrombi, RAA thrombi were much less common based on data from TEE, reported to be as low as 0.6–0.75% in AF patients [27]. Only one isolated solid thrombus was confined to RAA, accounting for 1.2% of all thrombi in our study. The atrial septal aneurysm had a prevalence of 2.4% in adults and had been reported to be a source of cardiac embolism in patients with otherwise unexplained ischemic stroke [11]. The formation of 2 sludge in the atrial septum aneurysm observed in our study, which had not been reported before, was due to slow blood flow stasis in the cavity during AF. This demonstrated that atrial septum aneurysm may be a potential site of thrombus formation.

The most common misdiagnosis of thrombus by TEE reported in previous studies include overdiagnosis of a mass shadow (false interpretation of prominent pectinate muscles or a reverberation artifact of the coumadin ridge) and underdiagnosis (occult thrombi in multilobed appendages) [28, 29]. Our study identified the presence of easily missed lamellar thrombus for the first time. Inconsistent with the results of previous studies, three patients with lamellar thrombus had a lower CHA2DS-2VASc score of 0–1 [30]. Importantly, a stroke/systemic embolism may be caused by detachment of the blood clot inside the atrial septum aneurysm or attached parallel to the atrial septum during the atrial trans-septal puncture and catheter ablation.

Conclusion

In patients with NVAF, this study identified two thrombus patterns: massive and a few lamellar. The distribution of thrombus and sludge outside limited to LAA was updated, including bilateral atrial and appendage involvement and rare atrial septal aneurysm sludge. Both the solid thrombus and sludge groups showed low LAAeV or LAAfV, which failed to identify the solid thrombus or sludge.

Limitation

This study was conducted at a single center and relied on observational, retrospective cohort data. More noninvasive echocardiographic parameters, including LA area, LA volume, LA volume index (LAVI), tricuspid annular plane systolic excursion (TAPSE), and potentially related to thrombus from previous studies, cannot be obtained. The study included a mix of patients, some with and some without anticoagulant therapy. Still, the proportion of patients receiving anticoagulant therapy was low, and there was no statistical difference between the solid and nonsolid groups. Because LAA flow velocities in AF are higher in diastole than in systole, longer cardiac cycles are associated with higher mean LAA velocities because of the prolongation of diastole [31]. The effect of lidocaine local anesthesia, which was used during TEE and may have increased heart rate on LAA velocities, is unclear. In our study, intravenously general anesthesia was widely used and could have reduced the impact on LAA flow velocities. Lastly, since the study is retrospective is retrospective in nature, routine TEE control to assess thrombus resolution could not be performed, and clinical outcomes could not be traced depending on various features of the thrombotic status.

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Author contributions
Ma CS and Dong JZ were responsible for the conception and design of the study. CJ collected and analyzed data, wrote manuscript. All authors reviewed and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study protocol followed the principles of the Declaration of Helsinki and received approval from the Human Ethics Review Committee of Beijing An Zhen Hospital. All patients provided written informed consent for inclusion.

Consent for publication
All authors approve the manuscript for publication.

Disclosures
None.

Competing interests
The authors declare no competing interests.

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