ECG-Gated Dual-Source CT for Detection of Left Atrial Appendage Thrombus in Patients Undergoing Catheter Ablation for Atrial Fibrillation

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ECG-gated dual-source CT for detection of left atrial appendage thrombus in patients undergoing catheter ablation for atrial fibrillation

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Abstract

Purpose Left atrial ablation is increasingly used to treat patients with symptomatic atrial fibrillation (AF). Prior to ablation, exclusion of left atrial appendage (LAA) thrombus is important. Whether ECG-gated dual-source computed tomography (DSCT) provides a sensitive means of detecting LAA thrombus in patients undergoing percutaneous AF ablation is unknown. Thus, we sought to determine the utility of ECG-gated DSCT in detecting LAA thrombus in patients with AF.

Methods A total of 255 patients (age 58±11 years, 78% male, ejection fraction 58±9%) who underwent ECG-gated DSCT and transesophageal echocardiography (TEE) prior to AF ablation between February 2006 and October 2007 were included. CHADS2 score and demographic data were obtained prospectively. Gated DSCT images were independently reviewed by two cardiac imagers blinded to TEE findings. The LAA was either defined as normal (fully opacified) or abnormal (under-filled) by DSCT.

Results An under-filled LAA was identified in 33 patients (12.9%), of whom four had thrombus confirmed by TEE. All patients diagnosed with LAA thrombus using TEE also had an abnormal LAA by gated DSCT. Thus, sensitivity and specificity for gated DSCT were 100% and 88%, respectively. No cases of LAA filling defects were observed in patients <51 years old with a CHADS2 of 0.

Conclusion In patients referred for AF ablation, thrombus is uncommon in the absence of additional risk factors. Gated DSCT provides excellent sensitivity for the detection of thrombus. Thus, in AF patients with a CHADS2 of 0, gated DSCT may provide a useful stand-alone imaging modality.

Keywords Computed tomography · Atrial fibrillation · Thrombus · Echocardiography

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1 Introduction

Catheter ablation of the left atrium is increasingly used in patients with symptomatic atrial fibrillation. In most cases, anatomic rendering of the left atrium and pulmonary veins using computed tomography (CT) is performed in addition to transesophageal echocardiography (TEE) to exclude the presence of thrombus in the left atrial appendage (LAA). Previously, we reported on the high sensitivity and specificity of ungated multi-detector CT (MDCT) in excluding LAA thrombus and providing detailed anatomic data of the left atrium and pulmonary veins [1].

An advantage of ECG-gated dual-source CT (DSCT) is that it provides better temporal and image resolution than ungated CT [2, 3]. Furthermore, ECG gating may attenuate the total radiation exposure as has been noted in prior studies [4–6]. However, whether ECG-gated DSCT also provides high sensitivity and specificity than ungated CT for the detection of LAA thrombus in patients undergoing percutaneous ablation for atrial fibrillation is unknown.

2 Methods

2.1 Patient population

Consecutive patients referred to the Mayo Clinic between February 2006 and October 2007 for left atrial catheter ablation for symptomatic atrial fibrillation were included. The study was approved by the Mayo Clinic Institutional Review Board (IRB) prior to data collection and analysis.

2.2 Pre-ablation imaging

Prior to the ablation procedure, all patients underwent ECG-gated DSCT and TEE. In most cases, CT and TEE were performed within 1–3 days of the procedure and in all cases within 3 days of one another to account for the possibility of clot formation between studies.

2.3 CT scanning

Gated contrast-enhanced CT of the chest was performed using a DSCT Somatom Definition (Siemens Medical Solutions, Forchheim, Germany) in supine position using a standardized protocol. A bolus of 150 ml of iodinated contrast media with a concentration of 300 mgI/ml (Iohexol/Omnipaque 300, GE Healthcare, Milwaukee, Wisconsin) was injected intravenously at an injection rate of 4 ml/s. After injection, there was a 5-s delay before the monitoring scan began in the ascending aorta. Images were then obtained every 2 s until the necessary threshold was achieved (up to 10 s to complete). Once the signal in the ascending aorta reached a predefined threshold of 150 HU, automated breath-hold instructions were given and the table moved into position to scan, typically 5 s in total before the scan was initiated. The entire volume of the heart was then scanned during one breath-hold during expiration within 15–20 s. The entire process from injection to complete scanning of the heart took approximately 40 s. No adjustments to the scans based on left atrium or left atrial appendage opacification were performed. The parameters for the acquisition in a craniocaudal direction were a gantry rotation speed of 330 ms per rotation, 120-kVp tube voltage, tube current time product of 350 mAs/rotation with a collimation of $2\times32\times0.6$-mm collimation and double Z-sampling. The pitch and the tube current modulation were adapted automatically to the heart rate of the patient. For ECG gating, a single segment reconstruction algorithm utilizing quarter scan segments from both detectors was applied to achieve a temporal resolution of 83 ms.

Reconstructions were performed with a B40f Kernel to generate 1.5-mm-thick slices with a reconstruction interval of 0.6 mm with a medium field of view (300 mm) centered at the heart. This produced an axial set of 300–400 images for review using an Advantage workstation or Vitrea workstation. This was the standard protocol and reconstruction and evaluation method for pre-ablation MDCT imaging at the time of this study at our institution.

All images were acquired and reviewed independently by two experienced cardiac imagers who were blinded to the results of the TEE. No attempt was made to "optimize" imaging of the LAA. No beta-blockers were given, and whether patients were in normal sinus rhythm or atrial fibrillation during image acquisition was not recorded. All images were reviewed simultaneously by both cardiac radiologists, and final interpretation in all cases was agreed upon by consensus.

The LAA was said to be "normal" if the entire LAA was filled with contrast and fully opacified (Fig. 1) or "abnormal" and "under-filled" if there was difficulty visualizing the entire LAA due to not being fully opacified with contrast media (Fig. 2). All images were viewed in the axial plane only without the use of multi-planar reconstructions or 3D volume rendering views. The use of "delayed" imaging of an under-filled LAA was not utilized for this study. Differences in the pattern or extent of the LAA filling defects were not systematically reported or compared to TEE.

2.4 Transesophageal echocardiography

Standard TEE was performed using a 3.5- to 7-MHz multiplane probe positioned at the appropriate level within the esophagus. For the left atrium and LAA, multiple views were recorded along with a "sweeping" view to optimize visualization of the entire structure with a careful search for the presence of thrombus within the left atrium or LAA. All images were acquired and interpreted by two echocardiographers blinded to the results of the DSCT. In cases where a pulsed wave Doppler signal was obtained at the mouth of the LAA, all the Doppler values were averaged and recorded. A definite thrombus was said to be present if an echo-dense material acoustically separate from the endocardium was found within the left atrial or LAA. No echo contrast agents were utilized in any of the TEE's to identify thrombus within the LAA. The LAA in each study was graded as none, mild spontaneous echo contrast (SEC), moderate SEC, severe SEC, or as thrombus based on

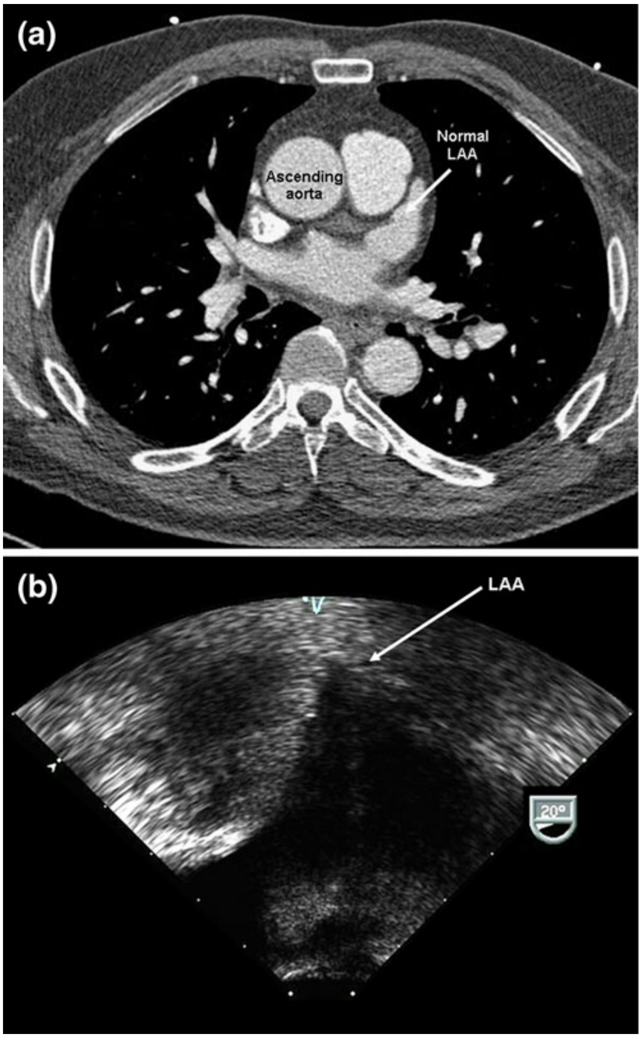

Fig. 1 No thrombus. Corresponding DSCT (**a**) and TEE (**b**) images demonstrating normal LAA without evidence of thrombus

previous descriptions [7, 8]. The finding of moderate SEC or above was considered abnormal.

2.5 Thrombus risk

Clinical stroke risk was calculated using the CHADS2 scoring system [9]. Decision to use warfarin was based upon the referring physician, and patients on warfarin had their anti-coagulation discontinued at least 2 days prior to the procedure and most often the day prior to DSCT or TEE. The decision to use bridging therapy with heparin while off warfarin was based upon clinical risk, presence of prosthetic heart valves, or other indications.

2.6 Statistical analysis

All data were entered into a database prospectively and analyzed retrospectively. Student's *t* tests were used to compare population averages, while Fisher's exact tests were used to calculate the statistical significance of categorical population differences. Sensitivity and specificity for the detection of clot on the basis of DSCT were determined assuming TEE as the gold standard for the detection of clot. The CHADS2 score was used as a single variable (the score value) to look for prediction of an abnormal filling defect. Categorical comparisons between groups were completed using a chi-square test for independence. All data were reviewed in a manner consistent with Mayo Clinic IRB requirements.

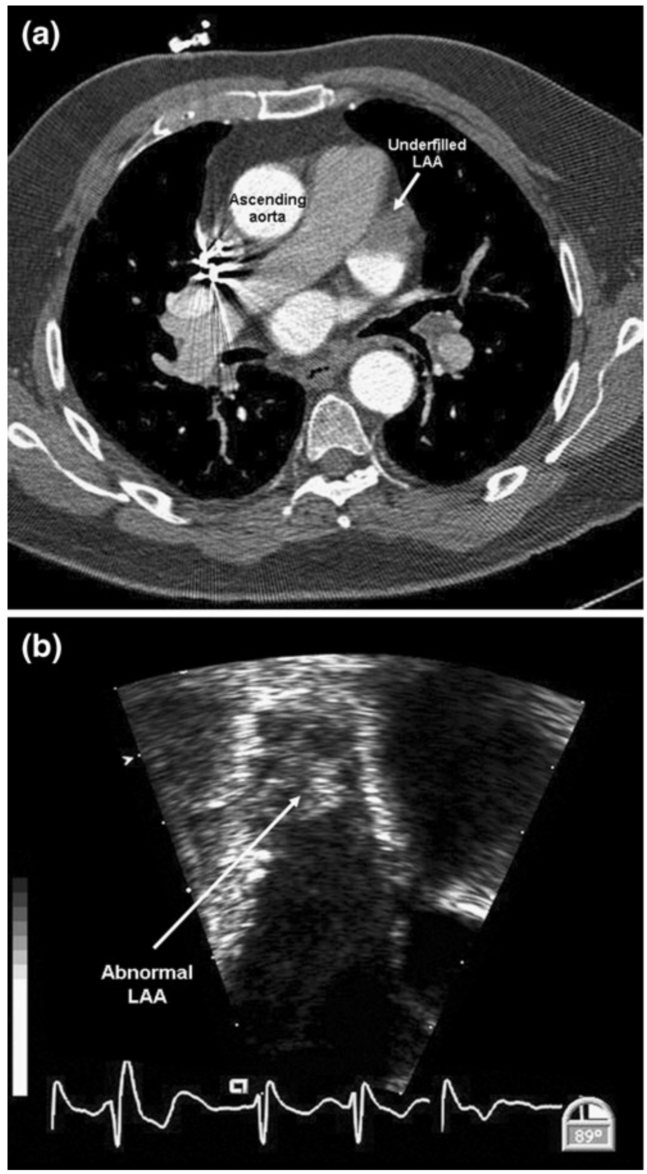

Fig. 2 Thrombus Present. Corresponding DSCT (**a**) and TEE (**b**) images showing thrombus present in the LAA. Note under-filling of the LAA on DSCT and opacification of the LAA on TEE consistent with the presence of LAA thrombus

2.7 Statement of responsibility

The authors had full access to the data and take responsibility for its integrity. All authors have read and agree to the manuscript as written.

3 Results

3.1 Study population

A total of 255 patients were included. Clinical characteristics of the study population are summarized (Table 1). Patients were of mean age 58±11 years with ejection fraction of 58±9 and were mostly male (78%) with 79% in atrial fibrillation at the time of imaging. The majority (78%) were therapeutically anticoagulated with warfarin prior to and during preoperative evaluation. All patients not anticoagulated with warfarin were on a daily aspirin.

3.2 Computed tomography

The LAA was considered to be normal in 222 patients (87%) and "under-filled" in 33 patients (13%). In 4 of the 33 patients (12%) with a filling defect on DSCT, TEE confirmed the presence of thrombus (Fig. 2). The majority of patients (85%) with an abnormal LAA were therapeutically anticoagulated with warfarin at the time of image acquisition.

3.3 Transesophageal echocardiogram

TEE was normal (no thrombus or moderate to severe SEC) in all 222 patients who had a normal LAA by DSCT. In 9 of the 29 patients (27%) with under-filling of the LAA on DSCT, but without evidence of a thrombus on TEE, at least moderate SEC or a decrease in LAA emptying velocities was present suggestive of "pre-thrombus."

3.4 Comparison between ECG-gated DSCT and TEE

Sensitivity and specificity of DSCT for the detection of thrombus were calculated assuming TEE as a "gold standard" for the detection of clot. On this basis, sensitivity and specificity for DSCT overall was 100% and 88%, respectively.

3.5 Clinical characteristics of patients with under-filled LAA by DSCT

A CHADS2 score was calculated for each patient and according to the presence or absence of a filling defect on DSCT (Table 1). The most common cardiovascular risk factor for stroke in association with atrial fibrillation was hypertension (45%), followed by heart failure (18%), prior history of stroke or transient ischemic attack (TIA, 6%), and diabetes mellitus (6%). Calculated CHADS2 score was not significantly different in patients with a normal LAA on DSCT versus those with underfilling of the LAA (0.7 versus 0.8, respectively). No differences were observed in age, gender, or left ventricular ejection fraction between groups.

No patients <51 years of age were found to have a TEE-confirmed thrombus in the LAA. Furthermore, of the 121 patients (47%) without any clinical risk factors for stroke based on the CHADS2 score who were referred for ablation, none had thrombus on the basis of TEE. The majority of patients (58%) with under-filling of the LAA on

Table 1 No thrombus versus under-filled CT

N=255	Normal LAA by CT (N=222)	LAA under-filled (N=33)	p value
Male, N (%)	172 (77)	27 (82)	0.83
Female, N (%)	50 (23)	6 (18)	0.68
Age, mean	59	57	0.32
Mean ejection fraction (%)	59	59	0.78
Persistent atrial fibrillation, n (%)	72 (32)	17 (52)	0.12
Paroxysmal atrial fibrillation, N (%)	150 (68)	16 (48)	0.17
Anticoagulation therapy, n (%)	171 (77)	28 (85)	0.67
Antiplatelet therapy, N (%)	88 (40)	15 (45)	0.55
Stroke risk factors			
Hypertension, N (%)	97 (44)	15 (45)	1.000
Diabetes mellitus, N (%)	26 (12)	2 (6)	0.28
Prior CVA/TIA, N (%)	7 (3)	2 (6)	0.29
LV dysfunction/HF, N (%)	31 (14)	6 (18)	0.63
Age over 65, N (%)	65 (29)	11 (33)	0.73
Mean CHADS2 score	0.7	0.8	0.64

DSCT had a CHADS2 score of at least 1, and 18% had a CHADS2 score of at least 2 (Table 2). In those with a confirmed thrombus by TEE, the CHADS2 score was significantly higher than in those with a normal LAA on DSCT (1.5 versus 0.7, $p=0.048$).

4 Discussion

The main finding of our study is that in addition to providing accurate rendering of the left atrium and pulmonary veins in patients undergoing left atrial ablation for atrial fibrillation, ECG-gated DSCT is a sensitive (100%) and specific (88%) imaging tool for the detection of thrombus within the LAA. Despite the low incidence of LAA thrombus in this population of patients undergoing left atrial catheter ablation, all were correctly identified by ECG-gated DSCT. To our knowledge, this study represents the largest cohort of patients in whom the role of ECG-gated CT for the detection of LAA thrombus has been examined and is the only study utilizing the high temporal resolution DSCT for this purpose [10–16]. Prior smaller studies have suggested varying degrees of sensitivity and specificity, with generally high specificities, and only one prior study demonstrating relatively low sensitivity (36%) [11–18] (Table 3). Our study benefits from the utilization of a standardized technique, protocol, and operators, thus allowing for greater homogeneity in the assessment of the LAA for filling defects and possible thrombus.

One advantage of DSCT over other gated MDCT modalities lies in its superior temporal resolution without the need for multi-segment reconstruction even at high heart rates, which allows for imaging of rapidly moving structures such as the LAA, and theoretically should offer improved visualization. In addition, DSCT provides rapid coverage of the heart in conjunction with ECG modulation techniques, resulting in radiation exposures that are often reduced over standard retrospective 64-slice MDCT [6, 17]. Furthermore, ECG gating could offer the ability to assess left ventricular ejection fraction, LA volume, and coronary artery status in a single examination. Thus, ECG-gated DSCT may have a role in certain clinical situations [19–21], and the benefits of gated versus ungated CT should be taken in the context of clinical utility outside of thrombus detection. We did not record the radiation exposure of the patients in this study. However, in general, it is well recognized that retrospective ungated CTs typically have lower radiation exposure compared with retrospective gated MDCT studies involving the same organ (i.e., chest, abdomen, head). Finally, the role of prospective gating for this purpose has not been well studied.

Previously, we reported on the sensitivity and specificity of ungated MDCT for the detection of LAA thrombus in a similar population of patients undergoing catheter ablation for atrial fibrillation and found similar sensitivity (100%) but slightly higher specificity (92%) when compared with ECG-gated DSCT [1]. Although the precise reason for the differences in specificity between these studies is not apparent, one likely possibility is over-reading of abnormal signals within the LAA in the present study. In addition, differences in gated versus ungated images during abnormal heart rhythm, for example atrial fibrillation, may have led to suboptimal visualization of the LAA.

4.1 Differences in risk of thrombus

Similar to findings in previous studies, we found a very low rate of thrombus in patients referred for atrial fibrillation ablation [1, 22]. Increasing CHADS2 score was not predictive of an abnormal DSCT, but was predictive of the presence of LAA thrombus by TEE. In our study, definite thrombus was not observed in any patients <51 years of age or without risk factors as defined by the CHADS2 score.

4.2 Study limitations

The major limitation of this study is that TEE, rather than direct visualization of the LAA for example at the time of surgery, was considered the “gold standard” so that in some cases, “sludge” or severe SEC could have been associated with a hidden thrombus, thus underestimating the specificity of DSCT. Thus, the rate of “pseudothrombus” as noted in prior studies, particularly with smaller numbers, may

Table 2 CHADS2 score

CHADS2 score	MDCT+ TEE+ (N=4)	MDCT+ TEE− (N=29)	MDCT+ TEE− (N=222)
0	0	14	107
1	2	11	76
2	2	3	35
3	0	1	3
≥4	0	0	1

Table 3 Summary of sensitivity, specificity, predictive values of CT versus TEE by prior studies

Study	No. of patients	Gating of CT scan	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)
Current study	255	ECG-gated dual-source CT	100	88	88	100
Martinez, et al. [1]	402	Non-gated multi-detector CT	100	92	23	100
Shapiro et al. [2][1]	43	Multi-detector CT	70	82	54	90
Burke et al. [3][2]	16	ECG-gated 16-row multi-slice CT	0 cases of thrombus	75	0 cases of thrombus	100
Patel et al. [11]	72	64-slice multi-detector CT	100	72	29	100
Kim et al. [12]	223	Multi-detector CT	93	85	31	99
Gottlieb et al. [13][3]	50	64-slice multi-detector CT	50–100	44–85	7–13	97–100
Jaber et al. [14]	31	3D multi-detector CT	100	100	100	100
Tang et al. [15]	170	64-slice contrast-enhanced CT	36	94	29	96
Singh et al. [17][1]	51	64-slice multi-detector CT	100	96	50	100
Achenbach et al. [18]	52	ECG-gated electron beam CT	100	87	54	100

Displayed are the sensitivities, specificities, and positive and negative predictive values for all prior studies comparing computed tomography and transesophageal echocardiography for the detection of left atrial thrombus [1]. Shapiro et al. and Singh et al. also used quantitative measures to differentiate thrombus via CT. Shown are the predictive values for identifying thrombus using visual identification of filling defects, similar to the procedure used in the present study [2]. Burke et al. [3] only had 16 patients undergo both TEE and CT and included no patients with thrombus. Gottlieb et al. determined inter-observer variability in their assessments of 50 different patients; shown are the ranges encountered for each of the three observers

have been significantly affected by the assessment of findings on TEE [23]. While some prior studies have demonstrated that dense non-clearing spontaneous echo contrast may be identified reliably via CT [11, 12], others have suggested that spontaneous echo contrast on TEE could not be consistently detected [2, 14, 18]. Further study is needed to determine if CT is adequate to detect dense spontaneous echo contrast that may otherwise preclude the decision to proceed with ablation.

A second limitation is that we did not determine whether “sludge” or SEC found during TEE correlated with filling defects seen on DSCT. However, the purpose of this study was not to prove that DSCT was superior to TEE but that DSCT could provide a sensitive means of ruling out thrombus in patients referred for atrial fibrillation ablation.

A third limitation is that, though unlikely, a new thrombus could have formed in the time between studies as the TEE and DSCT were performed as much as 48 h apart in most patients. Finally, the estimated radiation exposure was not recorded in this study, nor was utilization of prospective ECG gating MDCT.

4.3 Clinical implications

Our findings suggest that ECG-gated DSCT could be a useful imaging modality to “screen” for LAA thrombus, thereby avoiding the need for a TEE, which is not without risk [24], in addition to reducing cost, in patients undergoing complex ablation procedures that require ablation within the left atrium. These findings further those noted in prior studies and corroborate assessments that CT could be useful as some form of screening for left atrial thrombus [25]. The decision to perform a gated versus ungated CT should depend on the clinical question and the concern for radiation exposure based on patient age and gender as there is no significant benefit in gated over ungated CT in excluding LAA thrombus when comparing with results from prior studies [1].

5 Conclusion

Noninvasive imaging with ECG-gated DSCT prior to left atrial ablation in patients with atrial fibrillation not only provides accurate anatomic rendering of the left atrium and pulmonary veins but is also a sensitive (100%) and specific (88%) imaging tool to reliably exclude the presence of a left atrial appendage thrombus, especially in patients at low clinical risk. Thus, the absence of a filling defect on DSCT may permit atrial fibrillation ablation without a TEE. However, the presence of a filling defect on gated DSCT should not be a contraindication for ablation but rather an indication for TEE.

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Disclosures/Conflict of interest None.

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