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ORIGINAL PAPER

Exclusion of left atrial thrombus by dual-source cardiac computed tomography prior to catheter ablation for atrial fibrillation

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Abstract

Objectives Thromboembolic complications during atrial fibrillation (AF) ablation due to mobilisation of a pre-existing thrombus formation (TF) in the left atrium (LA) are devastating. The gold standard to exclude LA TF is transesophageal echocardiography (TEE). The present study compares sensitivity and specificity of a dual-source cardiac-computed tomography (DS-CT) with TEE for TF exclusion prior to AF ablation. In addition, CT protocols with and without ECG synchronized were evaluated.

Methods In 622 patients, DS-CT as well as TEE to exclude TF was performed less than 48 h prior to AF ablation. Mean age of patients was 60 ± 10 years (69% males, 61% paroxysmal AF). During DS-CT, 280 patients (45%) were in AF. An ECG-synchronized DS-CT was performed in 332 patients, whereas 290 patients underwent DS-CT without ECG synchronization.

Results In all patients without suspected TF on DS-CT ($n = 552$; 88.7%), no thrombus was found on TEE. A TF was suspected on DS-CT in 70 patients, of whom only three patients showed TF on TEE. No TF was detected in the other 67 patients (Fig. 1). Overall, sensitivity for TF detection in DS-CT was 100% and specificity was 89.2% (positive predictive value 4.3%, negative predictive value 100%). The CT protocol (ECG-synchronized versus non-ECG-synchronized) had no significant influence on diagnostic accuracy. Mean dose length product during DS CT was 282 ± 287 mGy cm (synchronized) versus 136 ± 55 mGy cm (non-synchronized) with $p < 0.0001$.

Conclusions DS-CT is a highly sensitive method for LA thrombus detection in patients undergoing AF ablation. It delivers additional anatomic details of pulmonary veins and LA anatomy with an acceptable radiation exposure. Non-ECG-synchronized DS-CT showed a significantly lower radiation exposure, whereas diagnostic accuracy was comparable. Therefore, DS-CT might serve as primary method to exclude LA TF in patients undergoing AF ablation.

Keywords Atrial fibrillation · Ablation · Dual-source cardiac-computed tomography · Thrombus exclusion

Objectives

Catheter ablation is regarded an established treatment option for patients with symptomatic paroxysmal and persistent atrial fibrillation (AF). Despite the use of preventive measures, a risk of periprocedural thromboembolic complications of 0.4–1.4% has been observed [1]. Thromboembolic complications due to the mobilisation of pre-existing thrombus formation (TF) in the left atrium (LA) are devastating and pre-existing TF is a contraindication for AF ablation [1]. The gold standard to exclude LA TF is transesophageal echocardiography (TEE) [2]. However, besides certain contraindications for TEE such as recent oesophageal surgery, it is a semi-invasive procedure with potentially life-threatening complications including aspiration and perforation. Furthermore, patients might experience physical discomfort and some may require analgosedation to tolerate the procedure [3, 4].

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An alternative technique to exclude LA TF might be dual-source cardiac-computed tomography (DS-CT), which also provides information of LA and PV anatomy, anatomical variations, location of the oesophagus and course and location of the phrenic nerve. All these information might contribute to a safer procedure. Published data suggest a varying sensitivity (30–100%) and specificity (88–96%) for LA TF exclusion compared to TEE. These studies mostly include older CT technologies such as multi-detector CT, whereas DS-CT was rarely used. Furthermore, data are only available in small populations [5–8]. A recently published review by Pathan et al. summarized the current evidence and stated that CT angiography is a safe and reasonable alternative to TEE for LA and LAA thrombus exclusion [9]. The present study compares the sensitivity and specificity of DS-CT with TEE for TF exclusion prior to AF ablation in a large cohort of patients. In addition, CT protocols with and without ECG synchronization were evaluated.

Methods

Patient selection

We prospectively included 622 patients (mean age of 60 ± 10 years; 69% male) who were scheduled for AF ablation from March 2012 to January 2015 at our department. Patients' clinical characteristics are summarized in Table 1.

After written informed consent, DS-CT as well as TEE were performed less than 48 h prior to ablation. Patients had paroxysmal AF in 61%, persistent in 36% and from atrial tachycardia in 3% of cases. A total of 280 patients (45%) were in AF during DS-CT. An ECG- synchronized DS-CT was performed in 332 patients as compared to 290 patients who underwent DS-CT without ECG synchronization.

Table 1 Clinical characteristics of the patients

Age (years)	60 ± 10
Male	*n* = 427 (69%)
Body mass index (kg/m^2)	27.4 ± 4.36
Arrhythmia	
Paroxysmal AF	*n* = 380 (61%)
Persistent AF	*n* = 224 (36%)
Atrial tachycardia	*n* = 13 (3%)
Within therapeutic INR range prior to ablation (yes)	*n* = 589 (95%)
Congestive heart failure	*n* = 195 (31%)
Hypertension	*n* = 432 (69%)
Diabetes mellitus	*n* = 57 (9%)
Previous stroke/TIA	*n* = 46 (7%)
CHA_2DS_2-VASc score	2.0 ± 1.5
ECG synchronized	
ECG synchronized	*n* = 332 (53%)
Non-ECG synchronized	*n* = 290 (47%)

ECG echocardiograph

Transesophageal echocardiography

In all patients, a TEE (iE33, Philips Healthcare, Best, Netherlands) using state of the art multiplane 4-7Mhz probes. To rule out TF in the LA, especially the left atrial appendage (LAA), 0-, 45-, 90- and 135-degree views were obtained. Pulse wave Doppler was employed to determine the flow velocity in the LA/LAA. Spontaneous echo contrast in the LA/LAA was defined according to Fatkin et al. into none, mild, moderate and severe [10]. Presence of a circumscribed homogeneous and echogenic mass in the LAA was defined as a thrombus. For display and evaluation, all images were recorded and stored digitally.

Dual-source cardiac computed tomography

All patients underwent DS-CT with a Siemens SOMATOM Definition Flash Dual-Source CT (Siemens, Forchheim, Germany). Scanning was performed using a contrast agent (CA) test-bolus technique via an 18-gauge needle placed into the right or left antecubital vein with a CA injection rate of 4–5 mL/s (Imeron 350, Bracco Imaging GmbH, Germany) followed by 50 mL of saline. Scan length was adjusted from the tracheal bifurcation to the apex of the left ventricle. Image acquisition was started 5 s after the measured time to peak enhancement in the ascending aorta preceding the DS-CT scan. Images were acquired during a breathing pause. The following scan parameters were used: detector collimation $2 \times 64 \times 0.6$ mm, slice acquisition $2 \times 128 \times 0.6$ mm, gantry rotation time 330 ms with a tube voltage depending on patients' weight between 100 and 120 kV. Tube voltage was manually adjusted with 100 kV in patients with a body mass index < 30 kg/m^2 or body weight < 90 kg and 120 kV for patients with a body mass index > 30 kg/m^2 or body weight > 90 kg. Maximum pitch was 3.4. Patients in SR underwent mostly ECG- synchronized DS-CT scans using a retrospective ECG-gated technique with data acquisition throughout the entire cardiac cycle with continuous ECG recording and retrospective image reconstruction of data acquired during mid-diastole. To reduce radiation dosage in those patients tube voltage modulation with ECG pulsing as described by Leschka et al. with tube voltage reduction during non-mid-diastolic phases was used [11]. Patients with AF, atrial tachycardia or frequent extrasystoles mostly underwent non-ECG– synchronized DS-CT scans (53%). Images collected during mid-diastole with 60–80% of RR interval were used and reconstructed. As recently shown by Trattner et al. a conventional conversion factor of 0.014 mSv (mGy cm)$^{-1}$ was underestimating radiation dosage for cardiac CT scans, therefore, a novel conversion factor of 0.026 mSv (mGy cm)$^{-1}$ according to recent findings was applied for dose estimation, nevertheless values for the old conversion factor are given in brackets due to comparability with older studies [12]. DS-CT scans were independently reviewed by an experienced radiologist and an experienced cardiologist blinded to TEE results. Disagreement was resolved by a joint reading. Depending on the contrast filling of the LAA, four entities were defined. Entities three and four were classified as TF.

1. Certain exclusion of TF in case of a complete and homogeneous contrast filling of the LAA without a filling defect.
2. Evidence of trabecular with a circumscribed CA gap and possible tracking of the trabecular from the LAA wall to the opposite wall.
3. Certain evidence of TF in case of a circumscribed CA filling defect.
4. Blurry, hard to define CA filling defect without the possibility to include or exclude TF (Fig. 1).

Statistics

Continuous variables were presented as mean ± standard deviation or median. The categorical data were expressed as frequencies and percentages. Univariate comparisons were performed using *t*-test (continuous variables) and χ^2 test. A *p* value of <0.05 was considered statistically significant. All analyses were performed using the SPSS for Mac version 20.0 (SPSS Inc., Chicago, IL, United States). Our local ethic committee approved this study.

Results

In all patients without suspected TF on DS-CT ($n=552$; 88.7%), no thrombus was found on TEE. A TF was suspected on DS-CT in 70 patients, of whom only three patients showed TF on TEE. No TF was detected in the other 67 patients (Fig. 1). Compared to TEE, the overall sensitivity for TF detection on DS-CT was 100% and specificity was 89.2%. Statistical analysis showed a positive predictive value (PPV) of 4.3% and a negative predictive value (NPV) of 100%. The prevalence of overall TF found in TEE was 0.5% ($n=3$) in this study (Table 2).

Patients with a CA filling defect on DS-CT significantly more often suffered from congestive heart failure (CHF) (34/70 pts, 49%) than patients without CA filling defect (161/552 patients, 29%) ($p<0.01$). Furthermore, patients with CA filling defect exhibited a higher CHA_2DS_2-VASc score of 2.4 ± 1.6 compared to patients without CA filling defect (CHA_2DS_2-VASc score of 1.9 ± 1.6) ($p<0.01$). Patients with non-paroxysmal AF showed significantly more often TF on DS-CT. Underlying rhythm during CT scanning had no influence in regard to a CA filling defect. The CT protocol (ECG synchronized versus non- ECG synchronized) had no significant influence on diagnostic accuracy ($p=0.11$). Comparisons of patients with and without CA filling defect are listed in Table 3.

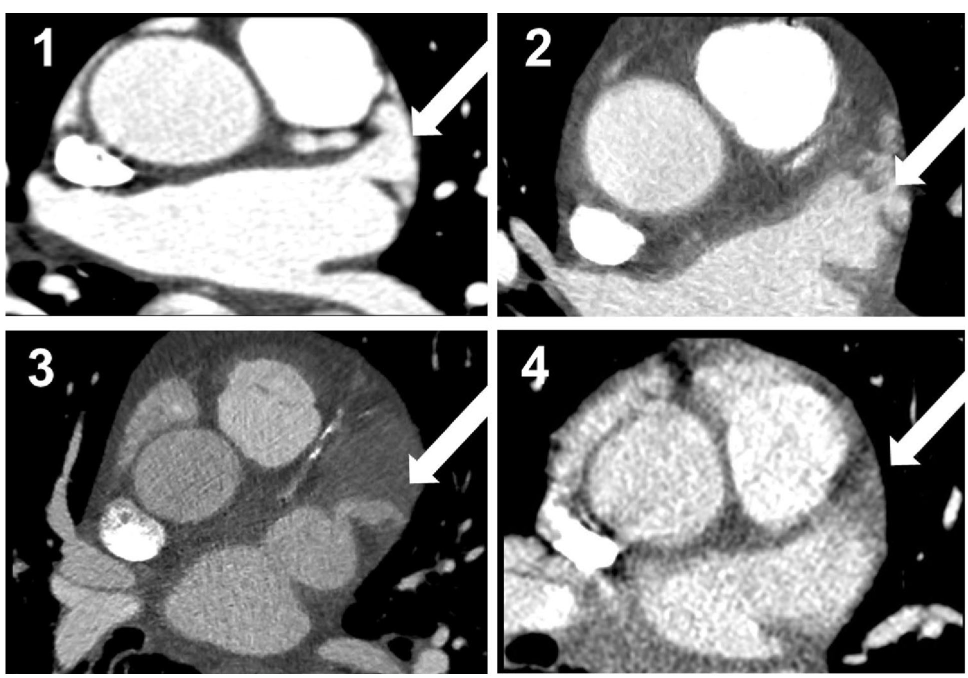

Fig. 1 Categorisation of LAA in DS-CT. (1) No thrombus formation. (2) Trabecular. (3) Thrombus formation. (4) Thrombus formation exclusion not possible. *DS-CT* dual-source cardiac computed tomography, *LAA* left atrial appendage

Table 2 Diagnostic performance of DS-CT for thrombus detection

	Thrombus in TEE	No thrombus in TEE	Total
Filling defect in DS-CT	$n=3$ (0.5%)	$n=67$ (10.8)	70
No filling defect in DS-CT	$n=0$ (0%)	$n=552$ (88.7%)	552
Total	3	619	622

DS-CT dual-source cardiac computed tomography, *TTE* transesophageal echocardiography

Table 3 Comparison of clinical characteristics for patients with and without contrast agent filling defect in DS-CT

	Suspected TF due to CA filling defect in DS-CT ($n=70$)	No TF in DS-CT ($n=552$)	p value
Age (years)	61 ± 10	60 ± 10	0.281
Male	$n=46$ (66%)	$n=381$ (69%)	0.574
Body mass index (kg/m^2)	27.9 ± 4.58	27.2 ± 4.33	0.247
Non-paroxysmal AF	$n=42$ (60%)	$n=200$ (36%)	< 0.01
Within therapeutic INR range prior to ablation (yes)	$n=65$ (93%)	$n=524$ (95%)	0.404
Congestive heart failure	$n=34$ (49%)	$n=161$ (29%)	< 0.01
Hypertension	$n=55$ (79%)	$n=377$ (68%)	0.08
Diabetes mellitus	$n=10$ (14%)	$n=47$ (9%)	0.115
Previous stroke/TIA	$n=8$ (11%)	$n=38$ (7%)	0.32
CHA_2DS_2-VASc score	2.4 ± 1.6	1.9 ± 1.6	< 0.01
ECG synchronized			
ECG synchronized	$n=31$ (44%)	$n=301$ (55%)	0.11
Non-ECG synchronized	$n=39$ (56%)	$n=251$ (45%)	
DS-CT in ongoing AF	$n=38$ (63%)	$n=242$ (48%)	0.174

AF atrial fibrillation, *DS-CT* dual-source cardiac computed tomography, *ECG* echocardiograph

The mean dose length product (DLP) was 222 ± 234 mGy cm. Radiation dose for DS-CT was 5.19 ± 4.85 mSv using a conversion factor of 0.026 mSv (mGy cm)$^{-1}$ (2.79 ± 2.61 mSv using a conversion factor of 0.014 mSv (mGy cm)$^{-1}$). The mean amount of CA used was 104 ± 18 mL. Comparison of ECG versus non-ECG–synchronized CT protocol had a significant influence on radiation exposure with a DLP of 282 ± 287 mGy cm and an estimated effective radiation dosage of 7.27 ± 7.47 mSv for ECG-synchronized CT protocols versus a DLP of 136 ± 55 mGy cm and an estimated effective dosage of 2.83 ± 1.90 mSv for non-ECG–synchronized CT protocols using a conversion factor of 0.026 mSv (mGy cm)$^{-1}$ ($p<0.0001$). Using the old conversion factor of 0.014 mSv (mGy cm)$^{-1}$ estimated effective dosage was 3.91 ± 4.02 and 1.52 ± 1.02 mSv. The amount of CA was significantly lower in patients with non-ECG- synchronized protocols with 94 ± 13 mL compared to patients with ECG- synchronized protocols (112 ± 17 mL) ($p<0.01$).

Discussion

To our knowledge, this is the largest study comparing the accuracy of left atrial thrombus detection between TEE and DS-CT prior to left atrial ablation. Our data demonstrate that DS-CT is a highly sensitive method for LA thrombus detection in patients undergoing AF ablation. Comparing DS-CT with the "gold standard" of TEE, no TF on TEE was overseen on DS-CT scans. A NPV of 100% DS-CT allows safe and accurate interpretation of potential TF and provides additional information of PV and LA anatomy.

TF is very uncommon in anticoagulated patients prior to LA ablation with an overall prevalence of only 0.5%. False-positive results were not uncommon (10.8%), especially in patients with non-paroxysmal AF, patients suffering from CHF or patients with a high CHA_2DS_2-VASc score. These findings are in line with published data with high NPV for DS-CT between 95.5 and 100% and a specificity between 88 and 96% [6, 7]. Of the three patients with "true" TF on TEE in our study, two patients had paroxysmal AF and were in SR during the DS-CT scan. Singh et al. proposed to delay image acquisition after CA admission to gain a more homogenous contrast of the LAA to reduce false-positive TF findings and improve specificity [13]. Recent studies could improve specificity up to 100% using a delayed image acquisition [14, 15].

Regarding radiation exposure, non-ECG- synchronized DS-CT showed significantly lower radiation and CA exposure with a comparable diagnostic accuracy. To address is the fact that TEE, of course, has no radiation exposure. However, it has to be taken into consideration that DS-CT delivers additional anatomic details. After DS-CT, pulmonary vein (PV) angiography is not necessary in most cases, therefore, leading to less radiation exposure during ablation. Information about potentially vulnerable anatomical structures such as the oesophagus or the phrenic nerve might help the operator to control the amount of RF delivery for example at the posterior LA wall, especially when using novel ablation catheters with contact force or enhanced irrigation [16–18]. Furthermore, as described by our group transseptal puncture can safely be performed using a combination of a 3D-mapping system and CT-derived 3D-overlay anatomy [19, 20]. This is especially helpful for patients with compounding anatomical circumstances such as atrial septal defect (ASD) occluder, atresia of the coronary sinus ostium or a funnel chest (Fig. 2). Furthermore, CT can help to detect patients which are more or less suitable for cryoballoon ablation depending on PV anatomy [21].

Following our results, non-ECG synchronized CT protocols with an estimated mean radiation dosage of 2.83 ± 1.90 mSv using the novel conversion factor of 0.026 mSv $(mGy\ cm)^{-1}$ and 1.52 ± 1.02 mSv using a conversion factor of 0.014 mSv $(mGy\ cm)^{-1}$ should be the preferred method to exclude TF prior to LA ablation. Especially the fact that a conversion factor of 0.026 displays radiation dosage in cardiac CT more accurately without systematically underestimating radiation dosage underlines the importance of DS-CT scans without ECG synchronization to reduce radiation exposure. Pulsation artefacts due to heartbeats result in sufficient accessibility of important anatomical structures such as PVs, LAA and the oesophagus but not the coronary arteries [22]. ECG- synchronized DS-CT should, therefore, be considered mainly in patients with a high pre-test probability for

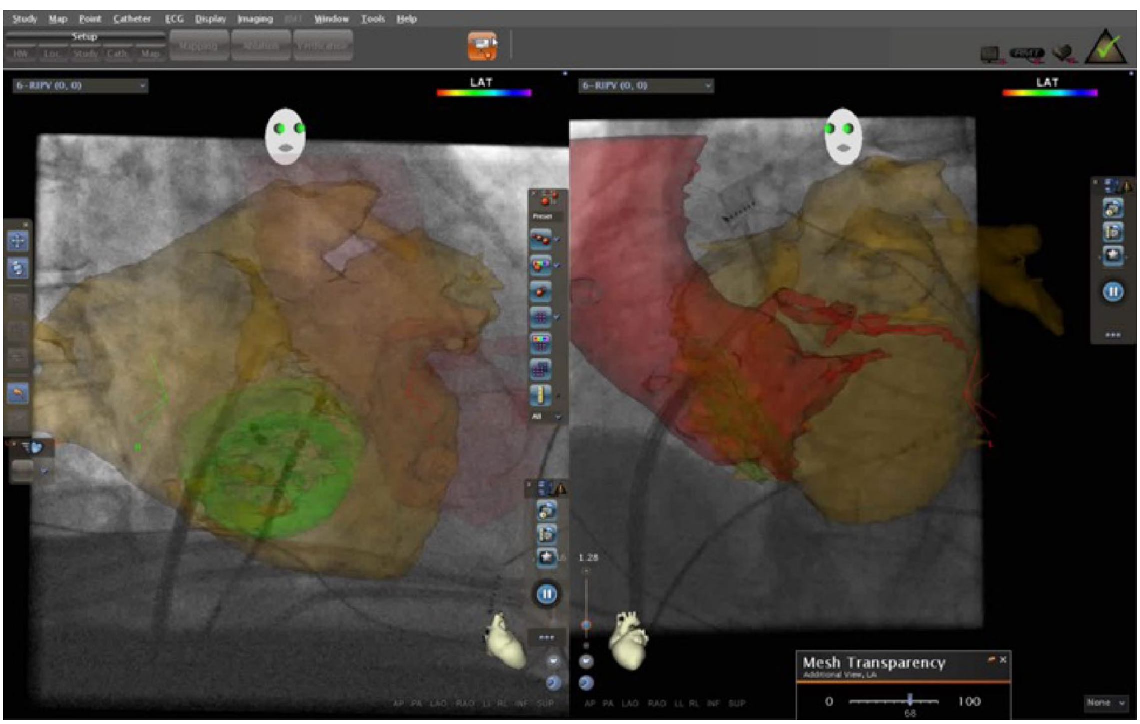

Fig. 2 Transseptal puncture in a patient with a large ASD occluder using the segmented DS-CT scan and CARTO 3. The CARTO3 Univu module was used to overlay the segmented 3D anatomy onto RAO and LAO fluoroscopic views. For registration, the 3D reconstructed spine, coronary sinus and the ASD occluder were congruently aligned to their fluoroscopic counterparts in RAO and LAO views. The RAO and LAO views with overlaid 3D anatomy in CARTO Univu verified the position of the transseptal needle at a suitable puncture site

coronary artery disease (CAD). Radiation exposure with a mean of 7.27 ± 7.48 mSv using a novel conversion factor of 0.026 mSv $(mGy\ cm)^{-1}$ and 3.91 ± 4.02 using a conversion factor of 0.014 mSv $(mGy\ cm)^{-1}$ is acceptable when compared to CAD exclusion using coronary angiography with an estimated typical effective doses of 9.3 mSv using a conversion factor of 0.026 mSv $(mGy\ cm)^{-1}$ and 5 mSv using a conversion factor of 0.014 mSv $(mGy\ cm)^{-1}$ [23]. Patients undergoing ECG synchronized DS-CT received a significantly higher dose of CA. As mentioned above, a retrospective ECG-gated technique with data acquisition throughout the entire cardiac cycle with continuous ECG recording and retrospectively image reconstruction of data acquired during mid-diastole was used. During one cardiac cycle, only 25–33% of the required images are acquired resulting in a longer image acquisition time compared to non-ECG synchronized scans, and therefore, resulting in higher CA dosages due to longer CA administration.

Last, to perform TEE only in patients with CA filling defect in DS-CT will lead to enhanced patient satisfaction and comfort as TEE is often experienced as unpleasant by patients.

Latest scanner techniques, novel image acquisition algorithms and ECG synchronization like high pitch CT protocols, a prospective acquisition protocol rather than a retrospective one can contribute to lower radiation dosages and less CA requirerment. A recently published analysis by Annoni et al. could show that ultra-low-dose CT for LA and PV imaging using a new model-based iterative reconstruction algorithm is feasible and allows examination with very low radiation exposure with estimated radiation dose of 0.41mSV without the loss of image quality [24, 25]. Regarding enhanced specificity using delayed phase imaging, a potential increase in radiation dose due to double CT scan is a concern. Therefore, different techniques like a two-phase protocol incorporating a second limited low-dose delayed contrast-enhanced examination of the LAA only or a double contrast, single phase CT scan by administering contrast twice with a delay between the first and second contrast bolus can be performed. Both techniques are resulting in reduced radiation dosage [26, 27].

Limitations

A limitation of the present study is the low TF prevalence of only 0.5%, which is most likely attributed to the high number of anticoagulated patients with paroxysmal AF and a low mean CHA_2DS_2-VASc score. The moderate specificity of DS-CT in this study is a major limitation and most likely due to fast image acquisition after test bolus injection without delayed LAA acquisition. Therefore, alternative approaches stated above should be used. Novel scan modalities result in a lower CA administration dosage. Furthermore, benefits of DS-CT scans must be balanced with potential side effects. Although radiation exposure, especially with a non-ECG-synchronized CT protocol is low, stochastic radiation damage has to be taken into consideration.

Conclusion

DS-CT is a highly sensitive method for LA thrombus detection in patients undergoing AF ablation. It provides additional anatomical details with an acceptable radiation exposure. Non-ECG-synchronized DS-CT demonstrated a significantly lower radiation exposure with comparable diagnostic accuracy. Therefore, DS-CT might be used as the primary method to exclude LA TF in patients undergoing AF ablation.

Compliance with ethical standards

Conflict of interest None declared.

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