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CARDIOVASCULAR IMAGING

ORIGINAL ARTICLE

Cardiac CT angiography after percutaneous left atrial appendage closure: early versus delayed scanning after contrast administration

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PURPOSE
Cardiac computed tomography angiography (CCTA) is increasingly used for device surveillance after left atrial appendage closure (LAAC). While CT protocols with delayed scans are useful to diagnose thrombus in the LAA, an optimal protocol for post-procedural CCTA has not been established. Therefore, we assessed the role of delayed versus early scans for device surveillance.

METHODS
We retrospectively reviewed patients who underwent LAAC at Vancouver General Hospital who had follow-up CCTAs using standard (early) and delayed scans. Scans were performed on Toshiba 320-detector (Aquilion ONE). Image quality was interpreted by 2 independent observers for anatomy, LAA contrast patency, and device-related thrombus (DRT) using Vitrea-Workstation™. A Likert scale of 1–5 was used (1= poor quality, 5= excellent) for assessment.

RESULTS
We included 27 consecutive LAAC patients (9 Amplatzer, 18 WATCHMAN) with mean age 76.0±7.7 years, mean $CHADS_2$ score 2.8±1.3, CHA_2DS_2-VASc score 4.4±1.6 and HAS-BLED score 3.4±1.0. Subjective quality assessments by both reviewers favored early scans for assessment of anatomy (reviewer 1: 4.63±0.63 [early] vs. 1.74±0.71 [delayed]; reviewer 2: 4.63±0.63 [early] vs. 1.89±0.64 [delayed]) and DRT (reviewer 1: 4.78±0.42 [early] vs. 3.11±1.16 [delayed]; reviewer 2: 4.70±0.47 [early] vs. 3.04±1.29 [delayed]). Inter-rater variability showed good correlation between reviewers (intraclass correlation 0.61–0.95). Mean LAA/LA attenuation ratios were significantly different between scans, with larger mean percent reduction of contrast opacification from LA to LAA in the early scans (57.0±36.6% reduction for early vs. 29.1±30.8% for delayed; $p < 0.001$).

CONCLUSION
For CT device surveillance post-LAAC early phase imaging provides superior image quality objectively and subjectively compared with delayed scanning.

Atrial fibrillation (AF) is the most common cardiac arrhythmia affecting 1%–2% of the general population, and 18% of patients who are 85 years or older (1). AF increases stroke risk by five-fold, and oral anticoagulation (OAC) is recommended for stroke prevention for AF patients at increased stroke risk (2). However, over 40% of patients with AF who have guideline-directed indications for OAC are not on anticoagulation because of contraindications, intolerance, non-compliance, or were deemed poor candidates for OAC by their physicians (3).

The left atrial appendage (LAA) is a trabeculated blind pouch in the left atrium (LA) located between the left ventricle and the left upper pulmonary vein (4). It has a complex and highly variable anatomy that is prone to thrombus formation in low flow states. Several studies of non-valvular AF patients showed that 91% of thrombi were located in the LAA (3, 5–11). Thus, targeted therapy with LAA closure (LAAC) had been explored as an alternative to OAC for stroke prevention. Contemporary usage of LAAC is mostly limited to patients with absolute or relative contraindications, or deemed poorly suited to OAC (3, 12).

Endovascular LAAC is a technically challenging procedure but advancements in technology and procedural techniques have improved safety and efficacy (3). Cardiac computed

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tomography angiography (CCTA) is increasingly used instead of transesophageal echocardiography (TEE) for pre-LAAC imaging because of its noninvasiveness and superior resolution, and three-dimensional depiction of LAA and surrounding structures. Although CCTA is highly sensitive for detecting LA and LAA thrombus, it can result in false-positive findings since filling defects may occur from impaired contrast mixing related to slow-flow with AF. CCTA protocols with delayed scanning have been shown to improve clot differentiation from slow flow in the LAA (13–15).

Post-LAAC, device surveillance is important to assess for residual leaks, device-related thrombus (DRT), device embolization, pericardial effusion, and impingement of neighboring structures. CCTA is also increasingly used instead of TEE for device surveillance post-LAAC (16); however, the optimal protocol timing of scanning (early versus delayed) to visualize device atrial-surface to differentiate thrombus from the device and surrounding structures have not been evaluated. Therefore, we performed comparisons of early versus delayed phase imaging for assessment of device and LAA post-LAAC.

Main points

- Cardiac computed tomography angiography (CTA) has become a well-established alternative imaging tool to transesophageal echocardiography (TEE) for left atrial appendage closure pre-planning. Although highly sensitive for detecting thrombus in the left atrium and left atrial appendage, filling defects due to impaired contrast mixing in atrial fibrillation can result in false-positive findings. Protocols with delayed scanning have been shown to improve clot differentiation from slow flow in the left atrial appendage in the context of pre-procedural planning.
- As post-procedural CTA focuses on different criteria in evaluation of procedural success after left atrial appendage closure (device-related thrombus, peri-device leak) a different imaging protocol seems to be necessary, which has not been reported yet.
- Cardiac CTA is a feasible, non-invasive alternative to TEE for follow-up imaging after left atrial appendage closure. In contrast to pre-procedural CTA our retrospective analysis comparing early and delayed scanning by 60–90 s in the context of post left atrial appendage closure surveillance favors early scans both in a subjective and an objective quality assessment.

Methods

We performed a retrospective analysis of patients who had CCTA post-LAAC with early and delayed imaging protocol at Vancouver General Hospital.

This study was not supported by any funding. The second delayed scan was performed as part of a quality control in our CT laboratory to evaluate the best imaging timing post-LAAC, thus, for this retrospective analysis, formal consent from the ethics review committee was not obtained. A second scan did not increase the patients` total radiation dose to a dangerous level according to the Radiologic Society of North America and the American Association of Physicists in Medicine (25), and no additional contrast dye was necessary. Therefore, we concluded that a second scan did not put the patients at any higher risk. This retrospective analysis was performed according to the Declaration of Helsinki principles. Informed procedural consent was obtained from all individual participants included in the study.

Percutaneous LAAC was performed with an Amplazter Cardiac Plug (ACP), Amulet or WATCHMAN device, and indications were non-valvular AF with high stroke-risk ($CHADS_2$ ≥1 or CHA_2DS_2-VASc ≥ 2) (17) and contraindication to long-term OAC. All patients had baseline imaging with CCTA and TEE at 4–8 weeks prior to LAAC. The technique for LAAC was previously described (18) and was performed under general anesthesia with TEE-guidance or under conscious sedation using intracardiac echocardiography. Post-procedure, patients were admitted overnight for observation. Antithrombotic regimen post-LAAC typically consisted of dual antiplatelet therapy (DAPT; aspirin + clopidogrel) for 1–3 months, followed by aspirin for ≥6 months (19).

Follow-up imaging with CCTA and TEE were performed 3–6 months post-procedure to evaluate for device position, embolization, atrial-side DRT, residual contrast leak (patency) into the LAA, and pericardial effusion. Glomerular filtration rate <30 mL/min/1.73 m^2 was an exclusion criteria for CCTA. To evaluate the usefulness of a delayed scan to image for DRT and residual LAA contrast opacification, we performed both early and delayed-phase scanning with our standard CCTA protocol post-LAAC (protocol described in Table 1).

Data acquisition

All scans were acquired on a 320 row Toshiba Aquilion One (Toshiba Medical Systems Corporation) scanner using a prospective systolic-triggered electrocardiography (ECG)-gated volume protocol. Two acquisition phases were done for each patient: (a) an early-phase, arterial acquisition with a delay determined by using real-time bolus tracking, and (b) a late-phase delayed acquistion 60–90 seconds after the initiation of the contrast injection. Patients were positioned supine, feet first in the gantry and

Table 1. CT protocol for post-procedure LAA closures with the Toshiba Aquilion One scanner

Prospective cardiac-gated scans	Values
Tube potential	100 kV for BMI <30 kg/m^2 120 kV if BMI >30 kg/m^2
Tube current	100–500 mA with ECG tube current modulation
Scan direction	Cranial to caudal
Scan volume	Heart to diaphragm (14–16 cm)
Size	Images reconstructed to 0.5 mm with 40% overlap, 512×512 mm matrix, FOV 18 –20 cm
Detector collimation	320×0.5 mm
Cardiac phase reconstruction	Relative triggering targeted at 35% of RR interval
Contrast bolus tracking	Sure Start
IV contrast injection (5 cc/s)	50–90 cc Omnipaque 350 contrast, followed by 50 cc 30% contrast/70% saline mixture, and final 30 cc saline chaser
Heart rate	No restriction
Beta-blocker and nitrates	Not required

CT, computed tomography; LAA, left atrial appendage; BMI, body mass index; ECG, electrocardiography; FOV, field of view; IV, intravenous.

dual scanograms were acquired at 90° for anatomical localization and scan planning. Early-phase scanning was initiated using real-time bolus tracking technique with a region of interest (ROI) placed in the descending aorta at the level of the mid-heart. A 50–90 mL bolus of non-ionic contrast material (Iohexol, 350 mg of iodine/mL, GE Healthcare) was injected via a power injector (Medrad Stellant CT System, Bayer Healthcare) through a large bore 18 G IV preferably placed in the antecubital fossa at a rate of 5 mL/s followed immediately by a 30 mL mixed bolus (30% contrast/70% saline) and then a 30 mL saline bolus. Image acquisition was automatically triggered when enhancement in the ROI reached 180 HU.

Both early- and late-phase images were acquired in a volume mode with the system detector width and acquisition speed allowing for a complete acquisition of the entire heart in one heartbeat. In brief, acquisition parameters were as follows: 350 ms gantry rotation time, 100 or 120 kV and mA ranging from 100 to 580 dependent on patient size, collimation of 0.5 mm and detector coverage of 160 mm in the Z-plane. ECG-based tube current modulation enabled radiation to be applied only to the target area of heart cycle and was set at a target of 35% relative to the R-R interval, which corresponds with late atrial diastole representing the phase of largest LA and LAA dimensions (20). Unlike coronary artery imaging, heart rate control was not mandatory as the system has an intrinisic temporal resolution of 175 ms, which is sufficient for evaluation of the relatively static LAA (21, 22).

Radiation exposure was estimated from the dose-length product (DLP) with a mean effective dose (ED) of 2.4 mSv for each early- or late-phase scan (23). ED was estimated by multiplying the recorded DLP by a chest-specific weighting factor of 0.014 mSv/mGy (According to European Commission guidelines for multislice computer tomography and the American Association of Physicists in Medicine) (24, 25). DLP per phase ranged from 33 to 369 mGy·cm, dependent on patient body habitus as the system employed automated tube current modulation and kilovoltage selection (100 or 120kV) relative to the patient size.

Images were reconstructed as follows: 0.5 mm section thickness, 0.3 mm increment, 512×512 pixel image matrix, medium smooth kernel, and 18–20 cm field of view. Digital images were interpreted on the VitreaWorkstation™ (Vital, Toshiba Medical Systems Group Company). We performed post-procedural CCTA image interpretation according to the LAA Occluder View for post-implantation Evaluation (LOVE), applicable for ACP/Amulet and WATCHMAN. This LOVE view (based on a standard CCTA protocol, same as for evaluation for coronary artery stenoses) was first described by Behnes et al. (26) and represents a standardized imaging proposal evaluating implanted LAAC devices by CCTA allowing optimal assessment of the most relevant clinical aspects in post-LAAC follow-up: peri-device leaks, coverage of LAA lobes, and indirect signs of neo-endothelialization. An absence of contrast enhancement within the LAA without any peri-device leak suggests complete neo-endothelialization, while contrast enhancement in the LAA of <50 HU compared to the LA suggests incomplete neo-endothelialization (26).

For quantitative objective analysis, LAA (distal to the closure device) and LA body mean attenuations (Hounsfield units, average out of three measurement) were measured on early and delayed phase CCTA images using 0.5 cm^2 regions of interest to calculate (a) LAA attenuation ratio (ratio of LAA attenuation on delayed to early phase), (b) LA attenuation ratio (ratio of LA attenuation on delayed to early phase), (c) LAA/LA attenuation ratio on early phase, and (d) LAA/LA attenuation ratio on delayed phase (27). In addition to this objective measurement, two independent CT reviewers (T.S.G., cardiologist; W.A., radiologist) subjectively assessed the quality of each of the two protocols regarding the ability to detect or rule out DRT. Each scan was evaluated according to a 5-point Likert scale: 1) poor: non-diagnostic, motion degrades image quality, anatomic details not delineated; 2) weak: uncertain to differentiate, mild anatomic delineation but not diagnostic; 3) average: borderline diagnostic, level of evidence decreased; 4) good: good LA contrast opacification with good anatomical delineation; 5) excellent: excellent LA contrast opacification with clear anatomical delineation. All CCTA measurements were performed blinded by the two reviewers, without knowledge of measurement values of the other.

CCTA findings were also compared with TEE, which were performed 3–6 months post LAAC and images were interpreted on position of the device, DRT, leak, pericardial effusion and visual estimation of the systolic left ventricular function. Clinical follow-up with regards to major adverse events (MAE: cardiovascular death, non-cardiovascular death, myocardial infarction, stroke/transient ischemic attack and major and minor bleeding events), as well as antiplatelet therapy post-LAAC, were obtained either via routine office visit or via telephone follow-up at 3 and 12 months post-LAAC, and annually thereafter.

Statistical analysis

Baseline characteristics were detailed by descriptive statistics. Continuous variables were summarized as mean±standard deviation, or as median and interquartile range. Categorical variables were summarized as frequency and percentage. Categorical variables were compared using chi-square or Fisher exact test, and continuous variables were compared with the paired t test. The relation between any two methods was determined using Pearson correlation, and the Bland-Altman method was used to assess agreement between two methods. Two-sided p value <0.05 was considered significant. The significance of differences in CT attenuation measurements were assessed by using the paired t test. Interrater variability between the two CT reviewers (T.S.G. and W.A.) with regards to the qualitative assessment of the scans was tested by the intraclass correlation coefficient (ICC) and Cohen's Kappa test. Statistical analyses were performed using SPSS software (IBM SPSS version 23) (19).

Results

We report 27 consecutive non-valvular AF patients who underwent percutaneous LAAC (4 ACP [14.8%], 5 Amulet [18.5%] and 18 WATCHMAN [66.7%]) between December 2016 and August 2017 who had early and delayed CCTA imaging post-LAAC. Baseline characteristics are described in Table 2. The mean age was 76.4±7.7 years, 15 (55.6%) were men and mean body mass index was 26.5±5.9 kg/m^2. Thirteen patients (48.1%) had a previous stroke or transient ischemic attack. The mean $CHADS_2$ score was 2.8±1.3, mean CHA_2DS_2-VASc score was 4.4±1.6, and mean HAS-BLED score was 3.4±1.0. All had contraindications to OAC. In 21 patients (77.8%), the procedure was performed under general anesthesia with TEE guidance; 6 patients (22.2%) had conscious

Table 2. Baseline characteristics, risk scores and bleeding history of patients

Variable	All (n=27)
Age (years), mean±SD	76.4±7.7
Men	15 (55.6)
BMI (kg/m^2), mean±SD	26.5±5.9
Hypertension	20 (74.1)
Dyslipidemia	16 (59.3)
Diabetes mellitus	8 (29.6)
Smoking history (active or remote)	18 (66.7)
COPD	6 (22.2)
Coronary artery disease	7 (25.9)
Previous myocardial infarction	4 (14.8)
Previous percutaneous coronary intervention	1 (3.7)
CABG	4 (14.8)
Heart failure	7 (25.9)
LVEF <40	6 (22.2)
History of valve surgery	3 (11.1)
Previous stroke/TIA	13 (48.1)
Systemic embolization	0 (0)
Permanent/persistent AF	16 (59.3)
Paroxysmal AF	11 (40.7)
Pacemaker/AICD	3 (11.1)
Creatinine (µmol/L), mean±SD	93.2±25.9
eGFR (MDRD) (mL/kg/1.73m^2), mean±SD	63.2±14.5
$CHADS_2$ score, mean±SD	2.8±1.3
CHA_2DS_2-VASc score, mean±SD	4.4±1.6
HAS-BLED score, mean±SD	3.4±1.0
Previous major bleeding	23 (85.2)
Previous major bleeding while on OAC	15 (65.2)
Intracranial bleeding	11 (40.7)
Major gastrointestinal bleeding	11 (40.7)
Other indications for LAAC	5 (18.5)
Hemoglobin at baseline (g/L), mean±SD	124.0±23.5
Platelet count at baseline (×103/µL) , mean±SD	210.8±75.1
Medication at baseline	
ASA	15 (55.6)
Apixaban	3 (11.1)
Warfarin	3 (11.1)
No antithrombotic/antiplatelet therapy	6 (22.2)

Data are presented as n (%) unless otherwise noted.
SD, standard deviation; BMI, body mass index; COPD, chronic obstructive pulmonary disease; CABG, coronary artery bypass graft; LVEF, left ventricular ejection fraction; TIA, transient ischemic attack; AF, atrial fibrillation; AICD, automatic implantable cardioverter-defibrillator; eGFR, estimated glomerular filtration rate; MDRD, modification of diet in renal disease; OAC, oral anticoagulation; LAAC, left atrial appendage closure; ASA, acetyl salicylic acid.

sedation with intracardiac echocardiography guidance. Procedural success was 100%. The mean size of implanted WATCHMAN devices was 29.3±3.2 mm, ACP was 25.0±2.0 mm and Amulet was 29.2±2.7 mm. The first attempted device was implanted in 21 patients (77.8%). The mean total procedural time was 74.9±44.9 min, mean fluoroscopy time 16.7±11.1 min, and mean contrast dye used was 82.0±35.2 mL. Of the 21 TEE-guided cases, there was one peri-device leak of 1 mm post-device release. One patient (3.7%) required urgent pericardiocentesis for pericardial tamponade several hours post-procedure. There were no other peri-procedural complications (deaths, strokes or transient ischemic attack, myocardial infarction, device embolization, or major/minor bleeding events). Pre-discharge transthoracic echocardiography (TTE) was performed in all patients, and no device embolization was noted.

Post-procedure, 25 patients (92.6%) were discharged on DAPT, one patient (3.7%) on aspirin alone and another (3.7%) on clopidogrel alone. The mean duration of DAPT was 37.2±31.3 days. Mean clinical follow-up was 15.6±8.2 months. There was one cardiovascular death (3.7%), which occured 7 months post-LAAC after prolonged hospital stay for back pain due to lumbar discitis and extensive epidural abscess, but the cause of death was unknown. One patient (3.7%) suffered a stroke within the first year after LAAC. This patient was on DAPT for one month and subsequently on aspirin for >6 months; 3-month imaging with TEE showed no DRT, leak or pericardial effusion, while CCTA showed a 4 mm peri-device leak. There was one major (3.7%) and one minor (3.7%) gastrointestinal bleeding on DAPT.

Post-procedural CCTA was performed at mean 101.3±21.4 days after LAAC, and the ED was 2.4±1.4 mSv (median, 2.3 mSv). All but one patient (n=26, 96.3%) underwent TEE within a few days from their CCTA scans. One patient declined follow-up TEE, and TTE was performed instead. Normal device position was confirmed in all patients with CCTA and TEE, and no relevant pericardial effusion (more than trivial) was reported with any modality. In 18 patients (66.7%), there remained contrast patency of the LAA (distal to the device) at the time of follow-up CCTA, whereas only 9 leaks (34.6%) were reported on TEE: minimal leak (<1 mm) was observed in two patients (7.7%), minor leak (1–3 mm) in four patients (15.4%), and moderate leak (3–5 mm) in two patients (7.7%) on TEE. No major leaks >5 mm were reported. DRT was diagnosed in one patient (3.8%) with CCTA, which was confirmed with TEE. This patient was temporarily switched from aspirin to warfarin with complete resolution of the DRT and had no complication.

For comparison of early and delayed CCTA, mean LAA/LA attenuation ratios on

early phases were significantly different from mean LAA/LA attenuation ratios on delayed phases (0.43±0.37 [95% CI, 0.28–0.57] for early vs. 0.71±0.31 [95% CI, 0.59–0.83] for delayed; $p < 0.001$), confirming a larger mean percent reduction of contrast opacification (measured in HU) from the LA to the LAA in the early scans compared to the delayed scans (57.0%±36.6% reduction for early vs. 29.1%±30.8% reduction for delayed; $p < 0.001$) (Fig. 1).

For evaluation of anatomy, the subjective quality assessment favored early phase CCTA to delayed phase images with a mean rating of 4.63±0.63 for early vs. 1.74±0.71 for delayed by T.S.G. and 4.63±0.63 for early vs. 1.89±0.64 for delayed by W.A.. There was no significant difference in the mean ratings of early phase measurements by T.S.G. and W.A. ($p = 0.99$) and none for delayed phase measurements by both ($p = 0.21$), but there was a significant difference between the early and the delayed phase measurements favoring the early phase, when comparing the mean ratings of both reviewers (4.63 early vs. 1.82 delayed; $p < 0.001$). The mean difference when the ratings of both reviewers were compared between the early phase and the delayed phase was 2.81±0.13 (95% CI, 2.56–3.06). The ICC for early phase measurements was 0.95 (95% CI, 0.89–0.98; $p < 0.001$) showing an excellent inter-rater reliability. For delayed phase measurements, the ICC was 0.75 (95% CI, 0.46–0.89; $p < 0.001$) revealing good inter-rater reliability. This was confirmed by a Cohen's kappa coefficient for early phase measurements of 0.84 ($p < 0.001$) and a kappa of 0.39 ($p = 0.01$) for delayed phase measurements, revealing very good and fair agreement between the two reviewers, respectively.

Similarly, early CCTA scans had superior quality for assessment of DRT compared to delayed scans (4.78±0.42 early vs. 3.11±1.16 delayed by T.S.G. and 4.70±0.47 early vs. 3.04±1.29 delayed by W.A.). When the mean ratings of both reviewers were compared, early phase measurments were favored compared to delayed phase measurements (4.74 early vs. 3.08 delayed; $p < 0.001$). The mean difference of both reviewers' ratings between the early phase and the delayed phase was 2.81±0.13 (95% CI: 2.56–3.06). There was no discrepancy between T.S.G. and W.A. in the mean ratings of early phase measurements ($p = 0.42$) or delayed phase measurements ($p = 0.57$). The ICC for early phase measurements was 0.61 (95% CI, 0.14–0.82; $p = 0.01$) and 0.92 (95% CI, 0.82–0.96; $p < 0.001$) for the delayed phase measurements showing moderate and excellent inter-rater reliability, respectively. This was again confirmed by a kappa coefficient of 0.43 ($p = 0.02$) for early phase measurements and a kappa of 0.62 ($p < 0.001$) for delayed phase measurements revealing moderate and good agreement between T.S.G. and W.A., respectively. Exemplary early and delayed phase CCTA images of two patients are shown in Fig. 2.

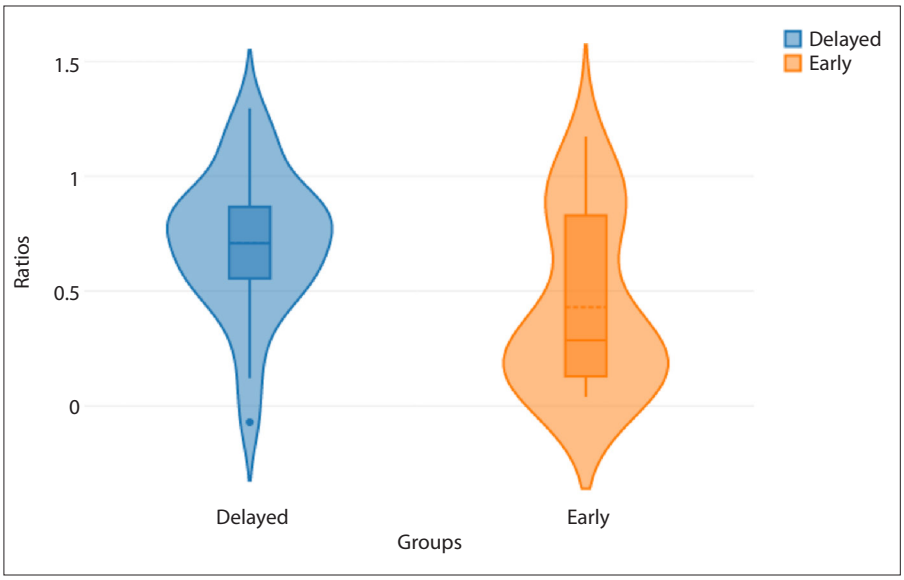

Figure 1. Distribution of delayed and early LAA/LA CT HU (Hounsfield units) ratios.

Discussion

Cardiac computed tomography angiography is a feasible, non-invasive alternative to TEE for follow-up imaging after LAAC. In this case series, we compared the image quality objectively and subjectively of early versus delayed CCTA scan post-LAAC for device surveillance. Unlike with pre-procedural CCTA where delayed scans improved ability to detect LAA thrombus, for post-LAAC scans, we found delayed scanning by 60–90 s to be inferior objectively and subjectively for image quality in device surveillance. Objectively, there was greater differential in attenuation ratio between the LA and LAA in early phase imaging, compared to delayed imaging. Subjectively, both reviewers preferred the early scans for interpretation of anatomy and DRT, compared to delayed scans. This finding makes sense, as an accentuated contrast between the blood in the left atrium and the device surface (and possible thrombus on top of it), which can be achieved with early phase scanning, helps in differentiating blood and thrombus at this level.

One important quality of CCTA in pre-procedural planning is its strong negative predictive value for thrombus detection in the LAA (96%–100%) (28–32), such that patients without filling defects on CCTA do not need TEE. This was made possible by adapting standard CCTA protocols using delayed imaging 30 to 60 s after contrast bolus. A filling defect due to sluggish flow should improve on delayed imaging, whereas a filling defect persisting on delayed imaging is more likely to represent thrombus (14, 15). This improved the positive predictive value for thrombus detection to 92% (14). Whether delayed imaging can improve assessment of DRT post-LAAC was not previously explored. Our hypothesis was that contrary to pre-LAAC CCTA, early scanning in post-LAAC surveillance would be beneficial as the region of interest changes from the distal part of the LAA to the proximal part and the LAA ostium, respectively, and it is therefore less relevant to have as much contrast opacification in the distal parts of the LAA but rather a stronger contrast at the level of the LAA ostium.

In our case series comparing early and delayed CCTA scans post-LAAC to detect DRT and residual LAA leaks (contrast opacification), the early scans were of superior quality compared to delayed scans. We did not find any benefit with delayed scans, and as a consequence, we discontinued routine delayed scanning for post-LAAC assess-

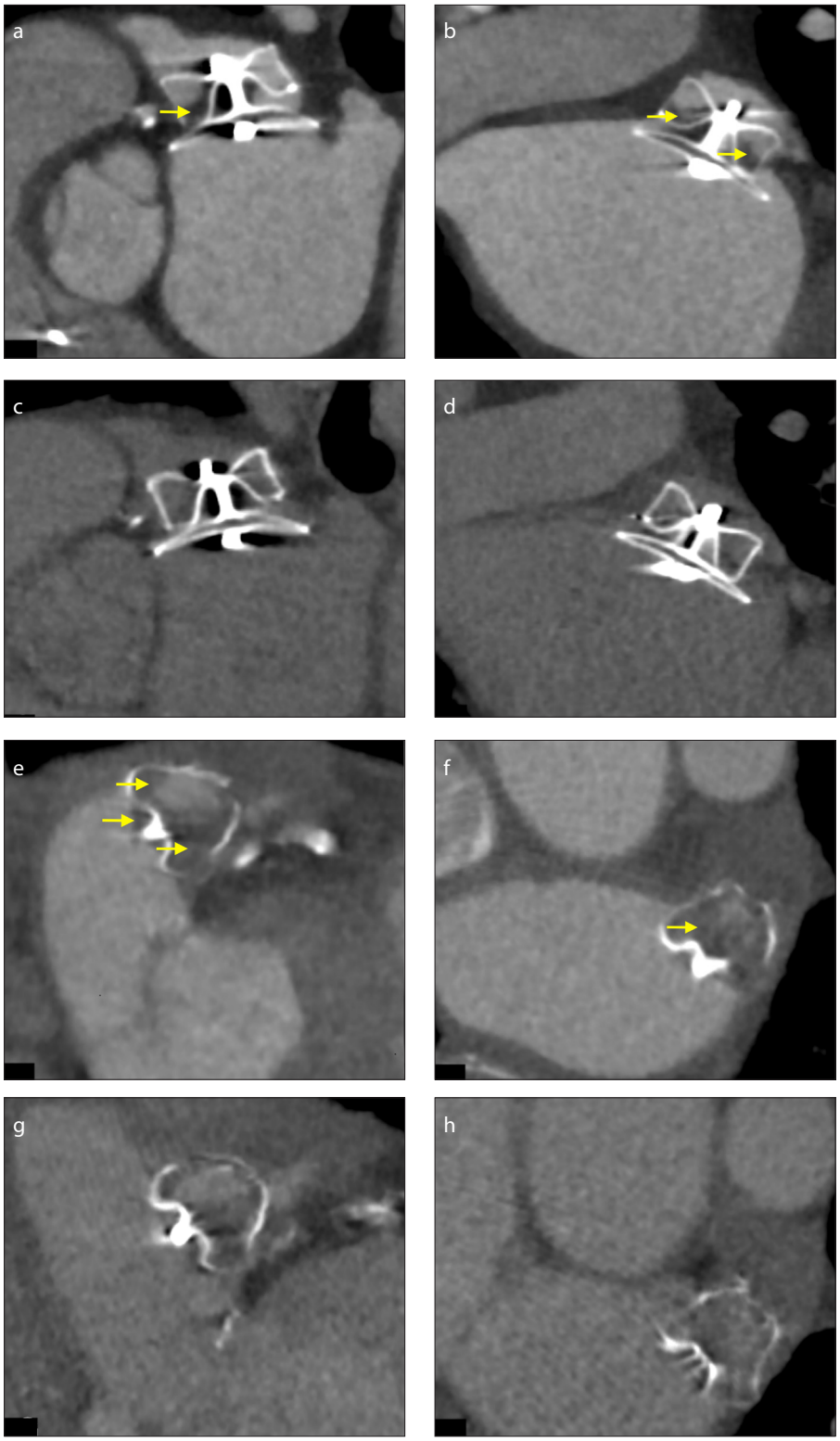

Figure 2. a–h. CCTA multiplanar reformat oblique planes images of early **(a, b)** and delayed **(c, d)** phase scans with an Amplatzer cardiac plug device in one patient. In the early phase images **(a, b)** there is excellent contrast opacification in the left atrium as well as behind the device resembling incomplete endothelialization or residual leak. Clear delineation between blood and thrombus *(arrows)* in the early phase images **(a, b)**. Delineation of anatomical structures and distinction between blood and thrombus are less clear in the delayed phase images **(c, d)**. CCTA multiplanar reformat oblique planes images of early **(e, f)** and delayed **(g, h)** scans with a WATCHMAN device in another patient. In the early phase images **(e, f)** thrombus *(arrows)* inside the device as well as on the surface of the device can be clearly delineated due to good contrast opacification in the left atrium. There is hardly any contrast behind the device resembling nearly complete seal of the device. Delayed scans **(g, h)** provide very little information on residual leakage and thrombus formation behind or on top of the device.

ment at our institution. Our current protocol (Table 2) includes contrast injection with a flow rate of at least 5 cc/s followed by a saline chaser in order to have a compact contrast bolus that is washed out mainly in the right atrium and right ventricle during image acquisition. CCTA acquisition protocols can include retrospective ECG gating, prospective ECG triggering, as well as high-pitch or single heartbeat acquisitions, to assess LAAC devices. For reconstruction of CCTA raw data, we use slice thickness between 0.5 and 0.6 mm with a sharp convolution kernel. If available, iterative reconstruction techniques should be used to lower image noise and blooming artifacts originating from metal components of the devices (26).

The advantages of CCTA for device surveillance include a) high spatial resolution; b) excellent three-dimensional relational depiction of the LAAC device and surrounding structures; c) accurate measurements of device compression in a nonfasting state with adequate volume status; d) fast acquisition; e) non-invasiveness; f) good accuracy to detect pericardial effusion, device embolization, peri-device leak (including sizing and localization of the leaks) and DRT. Compared to TEE, CCTA image acquisition is largely operator independent (21). The disadvantages of CCTA include (a) additional cost, (b) potential risks of radiation exposure, (c) contrast-induced nephropathy, extravasation, and allergy, and (d) training requirements to manipulate CT images and properly interpret the images (21).

The association between a completely occluded LAA and a linear attenuating coefficient (degree of attenuation, Hounsfield units) of <100 HU in the LAA, as well as an attenuation of <25% of the contrast opacification of the LA was previously described (19). Our study showed concordant findings for both the early and delayed scans, confirming no residual leak into the LAA according to this criteria. Post-LAAC, residual contrast opacification within the LAA can occur due to incomplete endothelialization (fabric-leak) or peri-device leaks (due to incomplete coverage of gaps at LAA ostia, or to off-axis device) (21, 33). As with prior studies (19, 33), we found higher prevalence of residual contrast opacification of the LAA on CCTA (67%) compared to peri-device leaks detected on TEE (35%) in our series. This confirms the superior sensitivity of CCTA to detect residual leak compared with TEE. However, the clinical

significance of small CCTA detected leaks have not been explored. In our series, one late stroke event occurred in a patient with a 4 mm leak on CCTA, which was not detected on TEE. Further research is necessary to assess the clinical relevance of residual LAA contrast opacification on CCTA (34).

The mean radiation dose with our standard post-LAAC CCTA protocol for surveillance is 2.4±1.4 mSv. For this study, the additional scan after 60 seconds resulted in a doubling of the radiation dose. This dosage is still considered relatively low. According to the 2011 position statement from the Radiologic Society of North America and the American Association of Physicists in Medicine, the risks of medical imaging at ED <50 mSv for single procedures are too low to be detectable and might be nonexistent (21). Nevertheless, less radiation is preferred, and abandoning delayed scanning for LAAC surveillance reduces radiation exposure without missing important information.

Our study is limited by the small sample size, retrospective nature, and with only one DRT detected in our series.

In conclusion, early phase imaging provides superior image quality for CT device surveillance post-LAAC compared with delayed scanning.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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