Split-Bolus Single-Phase Cardiac Multidetector Computed Tomography for Reliable Detection of Left Atrial Thrombus: Comparison to Transesophageal Echocardiography

Monophasische Doppel-Bolus-Kardio-Multidetektor-Computer-tomografie zur validen Detektion von Thromben im linken Vorhof und Vorhofohr: ein Vergleich zur transösophagealen Echokardiografie

Key words
- cardiac
- CT
- ultrasound

Abstract

Purpose: Evaluation of a new cardiac MDCT protocol using a split-bolus contrast injection protocol and single MDCT scan for reliable diagnosis of LA/LAA thrombi in comparison to TEE, optimizing radiation exposure and use of contrast agent.

Materials and Methods: A total of 182 consecutive patients with drug refractory AF scheduled for PVI (62.6 % male, mean age: 64.1 ± 10.2 years) underwent routine diagnostic work including TEE and cardiac MDCT for the evaluation of LA/LAA anatomy and thrombus formation between November 2010 and March 2012. Contrast media injection was split into a pre-bolus of 30 ml and main bolus of 70 ml iodinated contrast agent separated by a short time delay.

Results: In this study, split-bolus cardiac MDCT identified 14 of 182 patients with filling defects of the LA/LAA. In all of these 14 patients, abnormalities were found in TEE. All 5 of the 14 patients with thrombus formation in cardiac MDCT were confirmed by TEE.

Conclusion: MDCT was 100 % accurate for thrombus, with strong but not perfect overall results for SEC equivalent on MDCT.

Key Points:
- Patients with no filling defect or thrombus in MDCT in the LA/LAA region are unlikely to have thrombus and may undergo PVI without TEE.
- Here, the role of an additional TEE in pre-procedural management prior to PVI in patients with AF has to be redefined.
- Using a split-bolus injection protocol increases the diagnostic accuracy of thrombus in the LA/LAA region.

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Introduction

Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia with an associated risk of thromboembolism and significant increase of morbidity and mortality. Pulmonary vein isolation (PVI) by percutaneous radiofrequency ablation has evolved as an effective therapeutic option for this entity. It is currently recommended for drug refractory and symptomatic patients [1]. Prior to PVI it is mandatory to exclude left atrial (LA) and LA appendage (LAA) thrombus in order to prevent thromboembolic events during and after PVI [2–4]. In this context, there is no available biomarker to detect the presence of atrial thrombi and imaging is considered as the standard modality to obtain this information. Multidetector computed tomography (MDCT) and transesophageal echocardiography (TEE) are used prior to catheter ablation to exclude LA/LAA thrombus and provide exact anatomical details of the LA dimensions, as well as the number and anatomy of the pulmonary veins [5–8]. TEE is considered to be the standard of reference in the assessment of LA/LAA thrombus with a reported sensitivity of 100% and specificity of 99% [4]. In addition, TEE is able to identify spontaneous echo contrast (SEC) which is thought to represent a transitional state of slow flow prior to thrombus formation [6]. Recent studies have investigated the role of MDCT in the detection of LA/LAA thrombus with conflicting results and a wide range of diagnostic accuracy [7–12]. The main problem with most of the published scan protocols is the incomplete contrast enhancement of the LAA. To assess the risk of systemic thromboembolism, a number of clinical scoring systems have been defined. The CHADS2 score has been introduced as an effective clinical tool for the stratification of patients at risk for central or peripheral thromboembolic events. CHADS2 is an acronym for heart failure, hypertension, age > 75 years, diabetes mellitus and stroke. A negative predictive capability for thromboembolic risk is reported for low CHADS2 scores [5]. We used this novel MDCT technique with a dual-bolus contrast injection protocol in order to increase the diagnostic accuracy of cardiac MDCT in the diagnosis of LA/LAA thrombus and to compare it to the results from TEE. TEE as well as this cardiac MDCT protocol were correlated to the CHADS2 score. This study aimed to introduce an alternative noninvasive method to rule out LA/LAA thrombi with high diagnostic accuracy.

Materials and Methods:

Patient population

A total of 182 consecutive patients with drug refractory AF scheduled for PVI (62.6% male, mean age: 64.1 ± 10.2 years) underwent routine diagnostic workup prior to PVI including MDCT and TEE for the evaluation of LA/LAA anatomy and to rule out thrombus formation. All diagnostic and therapeutic procedures were performed at University Hospital Goettingen between November 2010 and March 2012. In all cases MDCT and TEE were performed within 1–3 days prior to PVI. The analysis was approved by the local ethics committee.

Multidetector computed tomography

Contrast-enhanced cardiac MDCT was performed using a 64-slice MDCT scanner (VCT LightSpeed, GE Healthcare, Milwaukee, WI, USA), slice collimation 64 × 0.625 mm; rotation time 600 msec; tube voltage 100–120 kV; adaptive dose regime (auto mAs, 280–380). Depending on the scan range and the patient’s body weight, the calculated mean radiation dose was 8.15 mSv (dose-length product range, 137 to 537 mGy ⋅ cm). Agreement between the detection of SEC and thrombi with CT and TEE was assessed with k statistics. A single spiral scan was done within a single breath-hold covering an area from the aortic arch to below the diaphragm. A retrospective ECG-gated half scan algorithm was used to reconstruct the data into contiguous axial images with a slice thickness of 0.625 mm. For this study a single phase reconstructed at 75% of the RR-interval was used for analysis. The scanner was not equipped with a prospective scan technique. Beta adrenergic blocking agents were administered before the scan procedure if the heart rate was > 70 bpm (79% of the investigated patients). Sublingual nitroglycerine was not administered due to the focus of the scan on atrial and peri-atrial anatomy. A split-bolus contrast media injection protocol was used: injection of 30 ml at 2 ml/s of iodinated intravenous contrast agent (Imeron 350, Bracco, Constance, Germany); a 20 s break followed by 70 ml at 4 ml/s of the same contrast and a 40 ml saline chaser at 4 ml/s. Semi-automatic bolus chasing was used to detect the second contrast bolus in the ascending aorta with a threshold of 100 Hounsfield units and a delay after triggering of 6 seconds. MDCT images were analyzed by two experienced independent readers blinded to the TEE results (P.Z., W.S.) on a separate workstation (VolumeShare2 on AW 4.2, GE Healthcare, Milwaukee, WI, USA). Atrial anatomy including pulmonary veins was identified for each patient. Qualitative, visual assessment of thrombus
formation in the LA or LAA was done using one of three categories: no thrombus, contrast filling defect or definite thrombus formation. A filling defect was defined as an intracavitary low attenuating oval or round lesion that represented incomplete mixing of contrast agent and blood [9]. Quantitative measurement of relative contrast enhancement of the LA and LAA to the ascending aorta was done in all patients. A 1 cm² region of interest was placed in the LAA or LA and the lumen of the ascending aorta (AAo) on the same axial plane. Relative contrast enhancement was calculated as the ratio of LA/LAA attenuation to AAo attenuation values of ≤0.5 according to previous studies [8, 17, 27] (Fig. 1).

Echocardiography
Transthoracic echocardiography (TTE) as well as transesophageal echocardiography (TEE) were performed in all patients. TEE was performed with a GE Vivid E9 ultrasound system (General Electric Ultrasound, Horten, Norway) using a 5.0 MHz multiplane probe acquiring continuous cine loops of LA/LAA in 0°–180°. TTE was used to determine LA size and left ventricular ejection fraction. Images were obtained according to methods described by the American Society of Echocardiography from the long axis, parasternal long and short axis, apical four-chamber and two-chamber views [13]. Highly experienced cardiologists performed and interpreted all TEEs. They were blinded to the patient’s history and results from other procedures such as MDCT. LA/LAA thrombus was defined as an intracavitary echogenic mass that could be differentiated from the surrounding tissue in at least two imaging planes. Thrombus was defined as a distinct intracavitary echodense or echolucent mass in comparison to dense non-clearing SEC, defined as a slow swirling smoke-like echodensity [8, 14, 15]. The teams of TEE/TTE and cardiac MDCT were blinded to the results of the other modality during the assessment of LA/LAA thrombus formation.

Clinical risk factors and anticoagulation
The CHADS2 scoring system [16–18] was used for the stratification of patients at risk for thromboembolic events. The scoring system assigns one point for the presence of heart failure, age > 75, diabetes mellitus and hypertension and two points for prior stroke or transitory ischemic attack (TIA). The CHADS2 score was calculated at the time of TEE. Further risk factors of LA/LAA thrombus like chronic kidney disease, valvular disease, cardiomyopathy and LA size were evaluated and documented but not included in the CHADS2 score [14]. The pre-procedural anticoagulation regime was adapted to the CHADS2 score. Phenprocoumon was used in the high-risk group (CHADS2 score > 1) with a target INR of 2.0–3.0. In the intermediate group (CHADS2 score = 1), anticoagulation therapy was based on the decision of the referring cardiologist. Patients in the low-risk group (CHADS2 score = 0) received aspirin or no anticoagulation therapy. Prior to catheter ablation, patients at high and intermediate risk were treated with phenprocumon for at least four weeks. Five days before catheter ablation, the patients were instructed to stop phenprocumon therapy. Bridging therapy with heparin derivatives (enoxaparin) was used in the high-risk group (100 IU/kg, s. c. twice a day).

Statistical analysis
Biostatistics were planned and performed by the local Department of Medical Statistics, University Hospital Goettingen. Student’s t-tests and Fisher’s exact tests were used to compare population averages and the statistical significance of categorical population differences or Chi-square test for categorical variables for independence between groups. Sensitivity, specificity, negative (NPV) and positive predictive values (PPV) were assessed assuming TEE as the reference standard for thrombus detection. Correlation analysis was performed using the Pearson coefficient (r).

Results
The demographic characteristics of all 182 consecutive patients are summarized in Table 1. The image quality of all 182 consecutive MDCT examinations was considered to be diagnostic for the evaluation of intracardiac findings. In all patients an LAA...
and LA assessment was feasible in all cases. The mean age was 64.1 ± 10.2 years with a male predominance (62.6 %). Paroxysmal AF was present in 65.4 % of patients whereas 34.6 % showed persistent AF. 78 % of patients were treated with phenprocoumon at anticoagulation. No adverse events were reported during TTE/TEE examination. Examinations were performed within 3 days (2 days ± 1). MDCT identified 14 of 182 patients with filling defects or thrombus formation in LA or LAA (Fig. 2). In 5 cases definitive thrombus formation was detected in LAA and confirmed by TEE; in 9 patients slow flow filling defects were identified and judged as thrombotic precursors in the state of circulatory stasis. TEE identified 16 of 182 patients with spontaneous echo contrast (SEC) in the LA or LAA. In the same 5 patients as identified in cardiac MDCT, TEE detected definitive thrombus formation in the LAA (Table 2). Of the remaining 11 patients with evidence of SEC, 9 patients showed corresponding changes of circulatory stasis filling defects in MDCT (3 of them with paroxysmal AF). Two cases of SEC-equivalence in TEE were missed by cardiac MDCT. Neither echocardiography nor MDCT identified thrombus or thrombotic precursors in the LA body. All pathologic changes were seen in the LAA. Detailed results are listed in Tables 3, 4. Assuming TEE as the standard of reference for the detection of thrombus or slow-flow filling defects, MDCT resulted in a sensitivity of 87.5 %, specificity of 100 %, a negative predictive value (NPV) of 98.8 % and a positive predictive value (PPV) of 100 %. There were no false-positive findings in MDCT in comparison to TEE. Quantitative analysis yielded a cut-off value for relative contrast enhancement of 0.5 (LA/LAA to Aao) for thrombus formation in LAA or LA: A LA/LAA to Aao relative contrast enhancement of ≤0.5 as proposed by Hur et al. [17] correlated to all detected thrombi by TEE. In comparison to TEE, there was no detected thrombus in MDCT with an LA/LAA ratio ≥0.5 (Fig. 1). Applying a value of ≥0.5 relative contrast enhancement in MDCT as a threshold of thrombus formation, the overall sensitivity, specificity, NPV and PPV were 100 %.

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### Table 1: Patient demographic characteristics.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No LA/LAA thrombus</th>
<th>LA/LAA thrombus</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>114 (62.1 %)</td>
<td>4 (80 %)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Female</td>
<td>68 (37.9 %)</td>
<td>2 (40 %)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Age, mean</td>
<td>64.03 ± 8.88</td>
<td>68.8 ± 12.89</td>
<td>n.s.</td>
</tr>
<tr>
<td>Mean ejection fraction</td>
<td>54.52 ± 5.98</td>
<td>48.60 ± 7.77</td>
<td>n.s.</td>
</tr>
<tr>
<td>Paroxysmal atrial fibrillation</td>
<td>116 (65.5 %)</td>
<td>3 (60 %)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Persistent atrial fibrillation</td>
<td>61 (34.5 %)</td>
<td>2 (40 %)</td>
<td>n.s.</td>
</tr>
<tr>
<td>LA size, mm</td>
<td>45.26 ± 6.86</td>
<td>50.20 ± 8.29</td>
<td>n.s.</td>
</tr>
<tr>
<td>Cardiomyopathy</td>
<td>9 (5.1 %)</td>
<td>0 (0 %)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Mitral/aortic valve disease</td>
<td>27 (15.3 %)</td>
<td>2 (40 %)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Serum creatinine, mg/dl</td>
<td>0.94 ± 0.27</td>
<td>1.12 ± 0.20</td>
<td>n.s.</td>
</tr>
<tr>
<td>Elevated serum creatinine</td>
<td>25 (14.1 %)</td>
<td>2 (40 %)</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

### Table 2: Clinical characteristics of patients with and without LA/LAA thrombus.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No LA/LAA thrombus</th>
<th>LA/LAA thrombus</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHADS 2 score:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHADS 2 = 0</td>
<td>41 (22.5 %)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHADS 2 = 1</td>
<td>92 (50.5 %)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHADS 2 = 2</td>
<td>36 (19.8 %)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHADS 2 ≥ 3</td>
<td>13 (7.1 %)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: Filling defects in MDCT and suspicious findings detected by TEE.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>MDCT thrombus or SEC</th>
<th>no thrombus or SEC</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrombus</td>
<td>14</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Slow-flow filling defects</td>
<td>2</td>
<td>166</td>
<td>168</td>
</tr>
</tbody>
</table>

### Table 4: Definite thrombus formation using LAA/AA ratio as a cutoff tool in MDCT, confirmed by TEE.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>MDCT thrombus</th>
<th>no thrombus</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrombus</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>No thrombus</td>
<td>0</td>
<td>177</td>
<td>177</td>
</tr>
</tbody>
</table>

Total 5 177 182

Sensitivity 100 %, specificity 100 %, NPV 100 %, PPV 100 %

Sensitivität 100 %, Spezifität 100 %, NPW 100 %, PPW 100 %
(6.8 % vs. 60 %, p-value < 0.0001) were significantly more prevalent in patients with LA/LAA thrombus. A subgroup analysis of patients with detected SEC on TEE revealed significantly higher CHADS2 scores than in patients without SEC (p = 0.02; r = 0.69). Significantly higher CHADS2 scores were more prevalent in patients with thrombus (CHADS2 ≥ 2; 18.6 % vs. 60 %, p-value 0.02 and CHADS2 ≥ 3; 6.2 % vs. 40 %, p-value 0.004). There was good interobserver agreement for mean LAA/AA HU ratios for thrombus, filling defect, and normal groups (r = 0.984, r = 0.948 and r = 0.920, respectively) (Fig. 3–5). The characteristics of the 5 patients (2.7 %) with LA/LAA thrombus are shown in Table 2.

Discussion

Main finding

This study aimed to prove the diagnostic accuracy of a split-contrast bolus in combination with single-phase cardiac MDCT in the clinical routine to rule out LA/LAA thrombi in patients with AF prior to PVI. The main finding of this study is that the presented contrast injection protocol combined with an LA/LAA to AAo HU ratio ≥ 0.5 on MDCT and a pre-procedural CHADS2-score of ≤ 1 were able to exclude thrombi with an NPV of 100 %.

Detection of LA/LAA thrombus formation prior to PVI

Prior to PVI it is mandatory to rule out LA/LAA thrombus formation to minimize the risk of periprocedural thromboembolic strokes during or after catheter ablation in the LA. In this context, TEE is known as an effective and reproducible method for ruling out intracavitary thrombi and it therefore currently remains the gold standard for assessing LA/LAA thrombus formation [2]. In many centers MDCT prior to PVI is usually performed to define the exact anatomy and dimensions of the LA and the insertions of the pulmonary veins. Within the same scan MDCT imaging is also used to rule out LA/LAA thrombus formation [17, 18]. Various study protocols for the detection of LA/LAA thrombus have been described and discussed in the past decade [9, 10, 17, 19–26]. Usually nonionic iodinated contrast agent is used in a single-bolus injection with monophasic or biphasic CT protocols [9–12, 17, 27]. It still remains a major limitation of MDCT that incomplete contrast filling of the LA is the most frequent cause of false-positive thrombus formation in the LA, leading to a low specificity and a low PPV of about 30 % [17, 18, 24].

MDCT in pre-procedural management prior to PVI

When using MDCT for the detection of LA/LAA thrombus in patients with AF, it still remains very important to reliably discriminate between thrombus formation and non-thrombotic filling defects. Recently, Hur et al. introduced an LA/LAA-AAo ratio of HU attenuation values [17] to evaluate thrombotic formations in the LA/LAA region. The mean HU values in the region of interest in the LA or LAA are divided by the mean attenuation value in the ascending aorta (AA). A cutoff value of ≤ 0.5 was shown by Hur et al. [17, 27] to represent thrombus formation in the LA/LAA region. In concordance with these findings, in the recent study all 5 thrombi detected in TEE were correctly identified on MDCT with 100 % diagnostic accuracy using LAA/AA ratio ≤ 0.5 as a cutoff value. Comparable to our study, Hur et al. [27] recently introduced a double-injection contrast protocol to overcome incomplete contrast filling of the LA/LAA. Biphasic MDCT resulted in a high sensitivity and specificity for the detection of LA/LAA thrombus, but it is associated with a significant increase in radiation exposure compared to single-phase cardiac MDCT [8]. To avoid an increase in radiation exposure with comparable PPV and NPV as seen with the biphasic MDCT protocol, we also used a split-bolus injection protocol with a pre-saturation of the blood pool and a second contrast injection boost during single-phase MDCT (Fig. 2, Table 3, 4).

Role of spontaneous echo contrast

Spontaneous echo contrast (SEC) in TEE is a common finding and can be found especially in patients with AF due to local circulatory stasis in the LA/LAA region [21, 22, 26]. It has to be considered that SEC is by definition not identical to thrombus formation in TEE and is therefore not a contraindication for the ablation procedure. Nevertheless, it has been described to be associated with a higher incidence of thrombus formation [23] in patients with AF and therefore SEC is an important finding in the pre-procedural management prior to an invasive ablation procedure in the LA [27]. Thus, Wazni et al. [23] reported no increase of peri-procedural stroke if SEC was identified in TEE and in addition even adequate anticoagulation did not have an influence on the degree or presence of SEC. Referring to this fact, in our study 11 patients showed SEC in TEE and 9 of 11 patients with SEC in TEE had non-thrombotic filling defects in MDCT defined as filling defects in the LAA with an LAA/AA ratio > 0.5. In two patients with detected SEC in TEE, no contrast abnormalities were detected in MDCT. The incidence of left atrial SEC rises with an increasing CHADS2 score which is in line with previous data from Scherr et al. [21]. The pre-saturation of the blood pool within the double-phase injection protocol consistently showed high HU attenuation values in the LA/LAA region. It seems to reduce non-thrombotic filling defects by more complete contrast filling of the LA and LA. The clinical interpretation of SEC (without thrombus) is still a clinical challenge. Probably, in the presence of structural changes, such as LA enlargement, a higher INR target should also be adopted in this specific setting. Further randomized studies are needed to confirm these results.
Risk factors for LA/LAA thrombus formation

Previous TEE studies in patients with AF undergoing PVI showed a wide range of LA/LAA thrombus prevalence (0.5% up to 13.8%) [19, 20]. Scherr et al. reported a 1.9% incidence of LA thrombus formation prior to PVI [21] in a cohort of 635 patients. This is in line with the findings of our study showing a prevalence of LA/LAA thrombus formation of 2.7%. It still remains questionable if there are certain risk factors that can reliably predict thrombus formation in patients with AF. As previously mentioned, it is common to use the CHADS2 score to validate for estimating the risk of cerebral thromboembolic stroke in patients with AF [5, 26]. An LA size of 45 mm evaluated at a 75% RR interval in MDCT and CHADS2 score $\geq 2$ were shown to be independent risk factors for LA/LAA thrombus in our study which is in concordance with the published literature [17, 18]. Apart from LA size and CHADS2 score, Dorenkamp et al. identified the presence of diabetes mellitus as a single independent risk factor of LAA thrombus [18]. In this context, all 5 thrombi identified by MDCT in our study were found in patients with a CHADS2 score of $\geq 2$ in combination with diabetes mellitus. There was no thrombus detected in MDCT or TEE in patients with an age $\leq 50$ and a CHADS2 score $\leq 1$. Despite an effective anticoagulation – based on a CHADS2 $\geq 2$ – 5 of 182 patients with AF undergoing MDCT and TEE prior to PVI showed LA/LAA thrombus formation.

Limitations

MDCT supplies high-resolution volumetric data sets of the heart and its related anatomical structures that are used to guide PVI. For optimal visualization of cardiac anatomy beyond the LA, we used the cardiac phase of 75% RR-interval of the retrospectively gated cardiac MDCT datasets. TEE was considered the reference standard, and the presence or absence of left atrium thrombus was not confirmed by direct visual inspection of anatomic or surgical specimen. Further studies need to evaluate the accuracy of thrombus detection in the LA/LAA region with an increased scan delay approach and/or using dual bolus strategies with an additional saline chaser after the first contrast medium injection. Despite that, TTE and cardiac MDCT were not performed on the same day. However, initial experience with dual-source CT (DSCT) at our institution using the same contrast injection protocol and a prospective trigger approach looks promising in regard to FPV and NPV for thrombus formation in the LA or LAA while significantly reducing radiation exposure to about $< 1 – 3$ mSv.

Conclusion

MDCT was 100% accurate for thrombus with strong but not perfect overall results for SEC-equivalence on MDCT. In the clinical...
routine, patients with no filling defect or thrombus in MDCT in the LA/LAA region are unlikely to have thrombus and may undergo PVI without TEE. This might redefine the role of an additional TEE in pre-procedural management prior to PVI in patients with AF.

Clinical implication

In patients with an LAA/AA ratio ≤ 0.5 on MDCT and a CHADS2 score ≤ 1, TEE may be safely avoided.

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