Left Atrial Mapping in Patients with Atrial Fibrillation: A Comparison Study of Image Quality and Radiation Dose Between High-Pitch Spiral CT Angiography and Retrospective ECG-Gated CT Angiography

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Abstract

Background: Trying to reduce radiation exposure from cardiac imaging is mandatory while maintaining diagnostic image quality (IQ). Using a high-pitch spiral dual-source computed tomography (DSCT) protocol for left atrial (LA) mapping, we sought to determine IQ and radiation dose in patients with atrial fibrillation scheduled for radiofrequency ablation.

Methods: Fifty-nine patients (29 women; mean age = 53 y) underwent CT angiography between 2013 and 2016: 26 patients with retrospective ECG-gated (classic) and 33 with high-pitch (Flash) protocols on a second-generation 128-DSCT system (SOMATOM Definition Flash). CT images of the LA were integrated into an electroanatomic system (NavX). Two independent blinded readers evaluated IQ using a 3-point scale and the LA contrast density. Dose-length product (DLP) was obtained from each patient protocol, and effective radiation dose (ERD) was calculated according to the European guideline for CT.

Results: The rate of diagnostic IQ (score 3 or 2) was 87.9% for the flash group and 96.2% for the classic group, which was not significantly different between the 2 groups (P = 0.250). The results of objective IQ measurements showed that a central LA contrast density above 350 Hounsfield units (diagnostic) was present in 21 (80.8%) images in the classic group and 26 (78.8%) images in the flash group, which was not statistically different between the 2 groups (P = 0.850). There were significant differences (P < 0.001) in DLP and ERD between the 2 groups: the values were lower in high-pitch scan than in retrospective ECG-gated scan (151.30 ± 39.44 vs. 776.61 ± 243.63 and 2.11 ± 0.55 vs. 10.872 ± 3.41, respectively).

Conclusions: High-pitch (Flash) DSCT is an acceptable CT angiography method for reducing radiation dose without compromising IQ for LA and pulmonary venous imaging in patients with atrial fibrillation.

Keywords: Atrial Fibrillation, Left Atrial Mapping, Dual-Source Computed Tomography, High-Pitch, Retrospective ECG-Gated, Image Quality, Radiation Dose

1. Background

Atrial fibrillation (AF) is the most common form of arrhythmia, with its incidence and prevalence increasing with age (1). It is understood that AF is triggered by ectopic beats from pulmonary veins (2), so the radiofrequency ablation (RFCA) of these electrical impulses can be a curative therapy for patients with refractory AF intolerant to antiarrhythmic medication or the primary method of choice in selected patients (3).

New ablation strategies are mainly based on anatomy. However, since there are several pulmonary venous anatomical variations (4), it is important to know detailed left atrial (LA) and pulmonary venous anatomies for successful ablation and also reduction of the procedure time (5).

Multi-detector row computed tomography (MDCT) angiography has been implemented successfully in several studies for characterizing the anatomy of the pulmonary veins and the LA before RFCA (6, 7). Particularly, MDCT is used for the integration of LA three-dimensional (3D) data into an electroanatomic mapping system such as NavX to navigate catheter ablation.

Despite its high radiation doses, which are mainly caused by low-pitch values and high tube-current settings, retrospective ECG-gated MDCT angiography is routinely performed as a method of choice in many centers (8). For example, in a multicenter, multi vendor trial, the median effective radiation dose (ERD) was 12 to 30 mSv (9). The association between high radiation exposure and cancer induction remains a major concern (10-13). Therefore, ac-
According to the ALARA (As Low As Reasonably Achievable) principle [14], the radiation exposure should be reduced while preserving diagnostic image quality (IQ). There are several techniques for radiation exposure reduction in cardiac computed tomography angiography (CTA) such as anatomic-based tube-current modulation [15, 16], ECG-based current modulation [17, 18], and reduced X-ray tube voltage [19].

With the invention of the second generation dual-source computed tomography (DSCT), low-dose high-pitch scan has been introduced enabling the entire heart to be scanned within 1 cardiac cycle and thus drastically reducing the radiation exposure to submillisievert values for certain coronary artery examinations [20]. To our knowledge, with the exception of a few studies, the existing literature has a dearth of data on the IQ and radiation dose of the different protocols of DSCT angiography for LA mapping [21-23].

In this study, comparisons of the IQ and radiation dose of 128-DSCT angiography were made in patients with AF scheduled for RFCA via 2 different protocols: conventional retrospective ECG-gated spiral scan and high-pitch spiral scan.

2. Methods

2.1. Patients

Due to the low radiation dose of high-pitch spiral CTA compared to the conventional protocol of retrospective ECG-gated spiral low-pitch CTA, there was no need to obtain written informed consent from the patients according to the HELSINKI standards. The institutional ethics committee approved the protocol of this study. Between 2013 and 2016 in Rajaie cardiovascular, Medical, and research center a tertiary care center for cardiovascular patients in Tehran, Iran we implemented 2 different CTA protocols using a 128-DSCT system for LA mapping on patients with AF. The patients were randomly allocated to the 2 different protocols before RFCA. The exclusion criteria consisted of previous adverse reactions to iodinated contrast agents, serum creatinine greater than 1.5 mg/dL, and respiratory uncooperativeness. During this period, 59 patients underwent CTA. IQ and radiation dose were compared between the 2 different protocols: 26 patients in the retrospective ECG-gated (classic) group and 33 patients in the high-pitch (Flash) group. Additionally, comparisons of IQ and radiation dose were performed between 2 subgroups of a high-pitch non-ECG-gated protocol with 20 patients and a high-pitch ECG-gated protocol with 13 patients.

2.2. DSCT Techniques

The 2 different cardiac imaging protocols of retrospective ECG-gated and prospective high-pitch Flash were performed using a second-generation 128-slice DSCT system (SOMATOM Definition Flash, Siemens Healthcare, Forchheim, Germany). All the imaging parameters regarding the imaging techniques were the same, except the gating system and the imaging pitch. The Flash data acquisition mode acquires imaging raw data at a pitch of 3.8 to 4 in a single heartbeat with a gantry rotation time of 0.28 second, usually at the diastolic phase, or non-gatedly. The retrospective ECG-gated cardiac imaging technique scans patients with a pitch range of 1 to 1.5 in several heartbeats and exposes patients during the entire cardiac cycle, which increases their received dose significantly.

In a single inspiration, all CT data were gathered in the craniocaudal direction from about 2 cm below the carina to the diaphragm. About 60 mL of intravenous contrast material lohexol (Omnipaque 350 mgI/mL, GE Healthcare, Fairfield, CT, USA) at a rate of 5 to 6 mL/s, followed by 50 mL of a saline chaser bolus, was infused in all the patients. The bolus-tracking technique was employed with a single attenuation threshold of 120 Hounsfield units (HU) in the ascending aorta. Data were acquired after 10 seconds. Image acquisition was accomplished under the conditions of CareDose and CareKV, which automatically modulate the current and voltage of the X-ray tube, respectively. The current and voltage of the X-ray tube were altered based on the patients’ weight, height, imaging volume thickness, and imaging territory which optimized IQ itself while reducing the patient dose dramatically. The reconstruction of CT images in the retrospective ECG-gated technique was heavily dependent on the patients’ heart rate and could differ from patient to patient. As a rule of thumb, the CT images relating to heart rates greater than 75 bpm were reconstructed in systolic phases, while the CT images relating to heart rates below 75 bpm were reconstructed during the cardiac diastolic cycle. The imaging slice thickness and increment were 0.6 mm and 0.4 mm, correspondingly. The reconstruction kernel was selected as B26f and was the same for all the patients and protocols in the study. The 3D CT images of the LA were integrated into an electroanatomic system (NavX, St Jude Medical; RPM, Boston Scientific, USA) to improve anatomic orientation and catheter navigation.

2.3. Assessment of Image Quality and Integration Success

Via transverse source image and maximum intensity projection (MIP), the subjective rating of IQ was independently performed by an experienced radiologist and a cardiologist, who were blinded to the patients’ demographic.
data and CTA protocols. A 3-point scale was used to score subjective IQ: 3 = excellent IQ, 2 = acceptable IQ, and 1 = poor IQ or nondiagnostic.

The LA contrast density was measured at the central portions (with a minimum area of 1 cm × cm) for the assessment of objective IQ with attenuation greater than 350 HU as diagnostic and attenuation less than 350 HU as nondiagnostic.

The integration of the data from 3D images into the NavX system was evaluated as being successful or unsuccessful.

2.4. Radiation Dose Estimates

Dose-length product (DLP) was obtained from each patient protocol and ERD was calculated as DLP multiplied by the appropriate conversion coefficient (k) for the chest (k = 0.014 mSv/(mGy cm)) according to the European guideline for CT.

2.5. Statistical Analysis

All the patients’ data were analyzed statistically using SPSS software (IBM Corp, 2013, IBM SPSS Statistics for Windows, version 22.0. Armonk, USA: NY: IBM Corp). A P value less than 0.05 was considered significant. The Kappa coefficient was calculated for intraobserver reliability. Percentages were used for the categorical variables and means ± standard deviations (SDs) for the continuous variables. The 2 study groups were compared using the independent-samples t-test or the Mann–Whitney U test for the continuous data and the χ² or Fisher exact test for the categorical variables, as appropriate.

3. Results

3.1. Patients

Our study population had a mean age of 48.15 ± 15.63 years in the high-pitch group and 58.15 ± 12.59 years in the retrospective ECG-gated group (P = 0.01). There were 14 (42.4%) females in the high-pitch group and 15 (57.7%) females in the retrospective ECG-gated group (P = 0.244). The patients’ baseline characteristics are depicted in Table 1.

<table>
<thead>
<tr>
<th>Variables</th>
<th>High-Pitch Flash</th>
<th>Retrospective ECG-gated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean, y</td>
<td>48.15 ± 15.63</td>
<td>58.15 ± 12.59</td>
</tr>
<tr>
<td>Male (%)</td>
<td>Female (%)</td>
<td>Male (%)</td>
</tr>
<tr>
<td>19 (57.6)</td>
<td>14 (42.4)</td>
<td>15 (45.5)</td>
</tr>
</tbody>
</table>

3.2. Image Quality

The intraclass correlation coefficients for inter- and intraobserver reliabilities of our measurements were greater than 0.9 for all the measurements, indicating an excellent intra- and interobserver agreement. The subjective IQ scores of the 2 CTA protocols are presented in Table 2. Figure 1 shows IQ by the different protocols utilized in our study. The rate of diagnostic IQ (score 3 or 2) of the 2 groups was 87.9% for the flash group and 96.2% for the classic group, which was not statistically different (P = 0.257). The subjective IQ scores of 18 (69.2%) patients in the classic group and 14 (42.4%) patients in the high-pitch flash group (6 patients in the Flash non-gated group and 8 patients in the Flash gated group) were excellent. Minor step artifacts (score 2) were observed in 7 (26.9%) patients in the classic group and 15 (45.5%) patients in the flash group (11 patients in the Flash non-gated group and 4 patients in the Flash gated group). Poor IQ (score 1) was noted in 1 (3.8%) patient in the classic group and 4 (12.1%) patients in the flash group (3 patients in the Flash non-gated and 1 patient in the Flash gated group).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Score 3</th>
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<th>Score 3</th>
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<tr>
<td>High-pitch Flash</td>
<td>14 (42.4)</td>
<td>15 (45.5)</td>
<td>4 (12.1)</td>
</tr>
<tr>
<td>Retrospective ECG-gated</td>
<td>18 (69.2)</td>
<td>7 (26.9)</td>
<td>1 (3.8)</td>
</tr>
</tbody>
</table>

*Values are expressed as No. (%).

The results of the objective IQ measurements showed that an LA contrast density above 350 HU (diagnostic) was present in 21 (80.8%) images in the classic group and 26 (78.8%) images in the flash group, with the difference not constituting statistical significance between the 2 groups (P = 0.850).

3.3. Integration Success

The results of the integration of the data from the 3D images into the NavX system are provided in Table 3. The integration was assessed as being successful in 25 (96.2%) patients in the classic group and 27 (81.8%) patients in the flash group, which was not statistically significant (P = 0.090). Unsuccessful procedures were observed in 1 (3.8%) patient in the classic group, 1 (7.7%) patient in the flash gated group, and 5 (25%) patients in the Flash non-gated group.

3.4. Radiation Dose

The radiation dose parameters are outlined in Table 4 for each protocol. DLP and ERD were much lower in the
The first row depicts the maximum intensity projection (MIP, Image A) and volume rendering (VR, Image B) of the non-gated Flash protocol. The second row represents the MIP (Image C) and VR (Image D) of the images of the ECG-gated Flash imaging protocol. The third row shows a clear view of the ECG-gated retrospective spiral computed tomography angiography MIP (Image E) and VR visualization (Image F). Although there is a slight left atrial (LA) ghost artifact (arrow) around its borders, it does not alter the LA mapping results significantly.

high-pitch scan than in the retrospective ECG-gated scan (151.30 ± 39.44 vs. 776.61 ± 243.63 and 2.11 ± 0.55 vs. 10.872 ± 3.41, respectively); the difference was statistically significant (P < 0.001). DLP and ERD were 140.53 ± 23.01 and 1.96
Table 3. Integration Results*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Successful</th>
<th>Unsuccessful</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-pitch Flash</td>
<td>27 (91.8)</td>
<td>6 (18.2)</td>
</tr>
<tr>
<td>Retrospective ECG-gated</td>
<td>25 (96.2)</td>
<td>1 (3.8)</td>
</tr>
</tbody>
</table>

*Values are expressed as No. (%).

± 0.32 in the flash gated group and 158.30 ± 39.44 and 2.21 ± 0.64 in the Flash non-gated group.

The workflow diagram is depicted in Figure 2.

4. Discussion

Our results demonstrated that not only did the novel protocol of high-pitch CTA on 128-DSCT provide diagnostic IQ for LA mapping before RFCA comparable to that of the routine retrospective ECG-gated CTA protocol but also it significantly reduced overall radiation exposure.

Motion artifacts are a reason for poor IQ in coronary CTA, particularly in high or irregular heart rates (24, 25). With the aim of minimizing the risk of motion artifacts, retrospective ECG-gated cardiac CTA has been implemented through the last decade as a protocol of choice for coronary CTA in AF (26-28).

Besides IQ, there is a need to optimize imaging techniques in order to reduce radiation exposure because of its association with cancer induction (29, 30). Pulmonary vein isolation is widely drawn upon for the management of patients with AF, who are exposed to significant radiation during fluoroscopy. Moreover, re-intervention and follow-up examinations are often needed for these patients because of AF recurrence or procedural complications such as pulmonary vein narrowing (31, 32). Accordingly, it is necessary to maintain the risk of radiation exposure as low as possible during CTA examinations.

There are various techniques available to reduce radiation exposure such as ECG-based current modulation (33), attenuation-based tube-current modulation (16), and tube-current and tube-voltage lowering (34). The most recently adopted option to reduce radiation exposure is increasing the pitch (35). A pitch of up to 3.4 can be implemented on the second generation 128-DSCT system, leading to a shorter radiation exposure time (36). Moreover, non-fluoroscopic catheter navigation can be performed during RFCA by the integration of the CT images of the LA and pulmonary veins into an electroanatomic mapping system (NavX) (37).

We believe that the present study is the first investigation to compare high-pitch and retrospectively ECG-gated protocols for the imaging of the LA and pulmonary veins in patients with AF.

We employed high-pitch spiral CTA and retrospective ECG-gated CTA for imaging the LA and pulmonary veins on 128-DSCT in patients with AF. Our data confirmed that arrhythmia did not influence IQ. Good diagnostic IQ was obtained by the high-pitch scan protocol and it was comparable with that of the retrospective ECG-gated scan protocol when applied for pulmonary vein imaging either in terms of subjective assessment (87.9% of the patients had excellent or acceptable IQ) or with respect to objective measures (78.8% of the patients had an LA density > 350 HU) in our patients with AF, which is in line with albeit lower than that reported by Thai et al. (22) and Cao et al. (23) (100%). This could be interpreted by the fact that the patients in our study showed AF ECG patterns much higher than those in the studies by Thai et al. (22) (26.6%) and Cao et al. (23) (55%).

An estimated mean ERD was 2.11 ± 0.55 mSv for the high-pitch flash scan, which was lower than that of the retrospective ECG-gated scan in our study (10.87 ± 3.41). Chiming in with our study, the mean ERD of the high-pitch protocol for imaging the LA and pulmonary veins was 1.2 mSv and 0.9 mSv in the studies by Thai et al. (22) and Cao et al., (23) respectively, which is lower than that of the retrospective ECG-gated sequential protocol in the study by Thai et al. (22) (19.3 mSv). The minimal differences in the radiation dose between these studies and our study can be explained first, by the different CTA settings based on the patients’ body mass index and second, by the extended field of view used in our protocols, resulting in a wide exposure window.

In addition, the results of our study demonstrated better IQ, more integration success, and lower radiation dose for the ECG-gated high-pitch protocol than for the non-ECG-gated high-pitch protocol. This finding is in contrast to the observations by Iwayama et al. (38). Larger samples are, however, required for a better evaluation.

The present study has a few limitations. There was possible selection bias for patients who underwent CTA. Some patients could not hold their breaths as long as needed; therefore, their image qualities were lower than the cooperative samples. We tried to participate the patients with full respiratory cooperation, so that their images would be free of motion artifacts. In addition, our final results may have been influenced by the subjective IQ scoring system bias.

4.1. Conclusions

A low radiation dose and a good diagnostic IQ are achievable with high-pitch DSCT for the imaging of the LA and pulmonary veins in patients with AF. In our study, the
Potentially Eligible Participants  
\( n = 68 \)

Excluded  
\( n = 9 \)  
- Previous Reactions to dye \( (n = 2) \)  
- Serum Creatinine > 1.5 mg/dl \( (n = 3) \)  
- Respiratory uncooperation \( (n = 4) \)

Eligible Participants  
\( n = 59 \)

High-Pitch FLASH CTA  
\( n = 33 \)

Non-ECG-gated FLASH  
\( n = 20 \)

ECG-gated FLASH  
\( n = 13 \)

Retrospectively ECG-gated CTA  
\( n = 26 \)

Diagnostic IQ \( = 87.9 \% \)  
Excellent Subjective IQ \( = 14 \)  
Minor Step Artifact \( = 15 \)  
Poor IQ \( = 4 \)  
Successful Integration \( = 27 \)  
Relatively Lower DLP

Diagnostic IQ \( = 92.2 \% \)  
Excellent Subjective IQ \( = 18 \)  
Minor Step Artifact \( = 7 \)  
Poor IQ \( = 1 \)  
Successful Integration \( = 25 \)  
Relatively higher DLP

Figure 2. Workflow Diagram of the Study

Table 4. Radiation Dose Parameters

<table>
<thead>
<tr>
<th>Variables</th>
<th>High-Pitch Flash</th>
<th>Retrospective ECG-gated</th>
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<tbody>
<tr>
<td>Mean DLP (mGycm) (± SD)</td>
<td>191.30 ± 39.44</td>
<td>776.61 ± 243.63</td>
</tr>
<tr>
<td>Mean ERD (mSv) (± SD)</td>
<td>2.11 ± 0.55</td>
<td>10.872 ± 3.41</td>
</tr>
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</table>

The radiation dose of the high-pitch scan protocol was drastically lower than that of the non-high-pitch scan protocol. This is a novel CTA protocol, which confers lower radiation exposure and could be a great imaging alternative for LA mapping before RFCA.

Acknowledgments

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