Low-Dose Computed Tomography Angiography for Preablational Imaging of the Left Atrium: Intraindividual Comparison to Magnetic Resonance Angiography

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Aims and objectives

Radiofrequency catheter ablation has evolved into a standard procedure in patients with paroxysmal or persistent atrial fibrillation since ectopic beats arising in the pulmonary veins (PVs) were recognized as very important triggers of atrial fibrillation\textsuperscript{1-3}. The standard preablational workup includes an evaluation using computed tomography angiography (CTA) or magnetic resonance angiography (MRA) for combination with electroanatomic mapping (EAM) as integral part of the registration process of the left atrium (LA) prior to ablation\textsuperscript{4,5}.

Both MR and CT images can be integrated into electroanatomic maps: Important advantages of CTA include the wider availability of CT scanners and, usually, a higher spatial resolution compared with MR images. The absence of radiation exposure is the most important advantage of MRA. Nonetheless, state-of-the-art CT techniques such as dual-source CT and wide-area detector CT scanners allow for considerably reduced radiation doses while maintaining a high image quality\textsuperscript{6,7}.

In this prospective study, we compared a low-dose single-beat acquisition CT protocol on a 320-row detector scanner and the standard clinical MR protocol at 1.5T for left atrial imaging in patients prior to ablation of atrial fibrillation and integrated the images into electroanatomic maps to evaluate the two imaging modalities in terms of image quality and applicability for image integration prior to ablational therapy.
Methods and materials

We included fifteen consecutive patients (13 men and 2 women) suffering from either paroxysmal or persistent atrial fibrillation in this prospectively designed and review board-approved study. After having given written informed consent patients were examined prior to radiofrequency catheter ablation on a 320-row wide-area detector CT system as well as on a 1.5T MR scanner.

CTA was performed after injection of a nonionic contrast agent (0.5 ml/kg of body weight) with the scan range adjusted to cover the left atrium. Rotation time was 350 s, and tube voltage was fixed at 100 kV except for one case, where it was raised to 120 kV due to a high body mass index (BMI). Scanning was performed during breath-hold at 75% of the RR-interval. The effective radiation dose associated with CT imaging was estimated using the dose length product as displayed on the scanner's console multiplied by a specific conversion factor for the chest \( k = 0.014 \text{ mSv} \times \text{mGy}^{-1} \times \text{cm}^{-1} \). MRA was performed at 1.5T using a 5-element cardiac synergy coil for signal reception. The sequence evaluated in this study was a non-electrocardiographically triggered 3-dimensional (3D) PV angiography (repetition time: 2.79 ms, echo time: 0.98 ms; flip angle: 27°; sensitivity-encoding factor of 2), performed after the administration of a gadolinium-containing contrast agent (0.2 ml/kg of body weight). Typical spatial resolution was 1.4 x 1.3 x 2.5 mm. Field of view was 400 mm and slab thickness 2.5 mm.

Overall image quality and PV anatomy was assessed independently by two readers. Image quality was rated as excellent (1), good (2), moderate (3), or poor (4). The number of PVs, the number of ostia, and the branching pattern of the PVs were assessed and PV diameters were recorded at the level of the ostium on reformatted axial images.

Additionally, segmentation of the CTA and MRA data sets was performed on an EAM system in the setting of the electrophysiological examination\(^5\) and segmentation times were recorded. The registration error between the surface of segmented LA and the mapping points of three-dimensional EAM was calculated automatically by the software of the EAM system and the accuracy of LA reconstructions was expressed as the mean distance between the EAM points and the surface of the segmented LA.
Results

CTA was performed either on the same day or one day after MRA. In most cases, cross-sectional imaging was performed one or two days prior to ablation, except for one patient, in whom anticoagulation due to an intracardiac thrombus had to be initiated; in this case, ablation was performed 33 days after CTA. CTA and MRA examinations were successfully completed in all patients. Mean dose-length-product (DLP) of CTA was 63.46 ± 40.87 mGy*cm, and mean effective dose was 0.95 ± 0.57 mSv.

Overall image quality of MRA was significantly lower than CTA image quality with median scores of 2 (good) for MRA and 1 (excellent) for CTA, with substantial agreement between the readers. Examples of excellent and good image quality for CT and MR are shown in Figure 1 and 2. Image quality of CTA was not found to be significantly influenced by the radiation dose. There was no significant difference across modalities in measuring the diameters of the PVs (Table 1). In terms of morphologic variants of the LA and the PVs, detection was equally well with CTA as with MRA, showing a common left ostium in 3 cases (reader 1), respectively 2 cases (reader 2) and a right middle accessory vein in 1 case for both readers. Ostial branching, which was defined as furcation of the PV in two or more separate branches within 1 cm of their origin of the left atrium\(^9\), was seen in 17 PVs by reader 1, and in 21 PVs by reader 2. Examples of a right middle accessory vein and ostial branching are shown in Figure 3 and 4, respectively.

Segmentation of CTA data with EAM was successful in all cases whereas segmentation was not possible with one of the MRA data sets due to an inadequate image quality. Segmentation times of CTA and MRA did not show a statistically significant difference, with CTA segmentation taking in median 1:39 minutes whereas MRA segmentation took 1:56 minutes in median. Surface-to-point distances (median number of mapping points: 82) of CTA and MRA were not found to differ significantly.
Fig. 1: Examples of excellent image quality on both axial CT (A) and MR (B) images in the same patient.

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Fig. 2: Examples of minimally reduced overall image quality in the same patient due to slightly blurred vessel wall contours (note the left lower pulmonary vein ostium) on CT images (A) and pronounced noise on MR images (B); in both cases, image quality was rated as "good".
Table 1: Median pulmonary vein diameters and interquartile ranges (IQR) across all pulmonary veins showing no significant difference across modalities in measuring diameters of the PVs. Due to inadequate planning of scan coverage, in one patient, the left upper pulmonary vein was not included on CTA images leading to different numbers of PVs assessed on CTA and MRA images. † T-test for multiple observations per patient

Fig. 3: Reformatted coronal images (A: CT, B: MR) showing a right middle accessory vein (white arrow).
Fig. 4: Ostial branching of a right lower pulmonary vein, indicated by the white arrow, on reformatted axial images (A: CT, B: MR).

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Conclusion

The ablation of atrial fibrillation is a technically challenging procedure for which a thorough understanding of left atrial anatomy is needed. Therefore, 3D EAM systems were developed about a decade ago to guide catheter ablation and a technique allowing for merging electroanatomic maps with CT- or MR-based 3D reconstructions was introduced into clinical practice. This technique requires preinterventional high-resolution imaging of the LA and the PVs.

In recent years, imaging of the LA has frequently been performed with retrospectively ECG-gated CTA leading to high data oversampling, and, consecutively, to a high radiation exposure. In the present study, we used a 320-row detector CT scanner with a detector width of 16 cm, which allows for prospective scanning of the entire heart in a single gantry rotation combining low radiation dose with minimized motion artifacts. Additionally, to keep radiation exposure as low as possible, the scan range was adjusted to only cover the LA and PVs. Thus, at a constantly high image quality, the total radiation exposure added up to 0.95 ± 0.57 mSv, which is comparable to or even lower than reported in the latest studies on CTA of the LA and the PVs. An advantage of MR imaging over CT imaging in patients with atrial fibrillation is the lack of radiation exposure. Standard MRA of the thoracic vessels is performed using contrast-enhanced first-pass 3D gradient-echo-sequences with an extracellular contrast agent. The imaging window for first-pass MRA is only one or two breath-holds, due to the inherent properties of the contrast agent. Thus, ECG-gating is precluded, which increases the likelihood of motion artefacts and reduces reproducibility of diameter measurements due to variations of PV diameter throughout the cardiac cycle. Nevertheless, the standard MR protocol for imaging of the LA and the PVs also showed high agreement to EAM, even though, in one case, image quality of MRA data sets was inadequate for merging which we related to motion artefacts as well as inadequate bolus timing.

In the current study, we introduced a low-radiation-dose ECG-gated CTA protocol in direct comparison to non-ECG-gated MRA of the LA and the PVs for merging with EAM. Our results demonstrate that both modalities provide similar imaging information on LA anatomy and ostial PV diameters and are both highly concordant with EAM - at radiation doses of about 1 mSv, concordance of ECG-gated CTA with EAM does not differ significantly from concordance of non-ECG-gated MRA with EAM.
References


