The association of left atrial low-voltage regions on electroanatomic mapping with low attenuation regions on cardiac computed tomography perfusion imaging in patients with atrial fibrillation

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BACKGROUND Previous studies have shown that contrast-enhanced multidetector computed tomography (CE-MDCT) could identify ventricular fibrosis after myocardial infarction. However, whether CE-MDCT can characterize atrial low-voltage regions remains unknown.

OBJECTIVE The purpose of this study was to examine the association of CE-MDCT image attenuation with left atrial (LA) low bipolar voltage regions in patients undergoing repeat ablation for atrial fibrillation recurrence.

METHODS We enrolled 20 patients undergoing repeat ablation for atrial fibrillation recurrence. All patients underwent preprocedural 3-dimensional CE-MDCT of the LA, followed by voltage mapping (>100 points) of the LA during the ablation procedure. Epicardial and endocardial contours were manually drawn around LA myocardium on multiplanar CE-MDCT axial images. Segmented 3-dimensional images of the LA myocardium were reconstructed. Electroanatomic map points were retrospectively registered to the corresponding CE-MDCT images.

RESULTS A total of 2028 electroanatomic map points obtained in sinus rhythm from the LA endocardium were registered to the segmented LA wall CE-MDCT images. In a linear mixed model, each unit increase in the local image attenuation ratio was associated with 25.2% increase in log bipolar voltage (P = .046) after adjusting for age, sex, body mass index, and LA volume, as well as clustering of data by patient and LA regions.

CONCLUSION We demonstrate that the image attenuation ratio derived from CE-MDCT is associated with LA bipolar voltage. The potential ability to image fibrosis via CE-MDCT may provide a useful alternative in patients with contraindications to magnetic resonance imaging.

KEYWORDS Atrial fibrillation; Cardiac computed tomography perfusion imaging; Electroanatomic mapping

ABBREVIATIONS 3-D = 3-dimensional; **AF** = atrial fibrillation; **CE-MDCT** = contrast-enhanced multidetector computed tomography; **CI** = confidence interval; **CT** = computed tomography; **EAM** = electroanatomic map; **IAR** = image attenuation ratio; **LA** = left atrium/atrial; **LGE** = late gadolinium enhancement; **MRI** = magnetic resonance imaging; **PV** = pulmonary vein

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Introduction

Atrial fibrillation (AF) is the most common arrhythmia and is associated with increased risk of stroke, heart failure, and mortality.[1–3] Although success rates for maintenance of sinus rhythm after ablation are reasonable,[4] the procedure remains limited by recurrences.[5–7] Atrial remodeling and fibrosis have been found to be associated with the recurrence of AF.[8] The location and extent of late gadolinium enhancement (LGE) on magnetic resonance

imaging (MRI) have been demonstrated to benefit patient selection and assessment of ablation efficacy.[9,10] However, LGE MRI has limited spatial resolution, requires extensive expertise for proper image acquisition and analysis, is not tolerated by some patients owing to claustrophobia, and is contraindicated in patients with metallic implants.[11] Recent studies[12–15] have shown that contrast-enhanced multidetector computed tomography (CE-MDCT) can visualize ventricular fibrosis after myocardial infarction in experimental animals and patients. In patients with ischemic cardiomyopathy, hypoperfusion segments on CE-MDCT images matched well with abnormal voltage segments.[15] We sought to test the hypothesis that low-voltage left atrial (LA) myocardium also has lower perfusion and consequently lower image attenuation on perfusion CE-MDCT.

Methods

Patient characteristics

The study cohort includes 20 patients who underwent repeat AF ablation at our institution from November 2012 to December 2013 for recurrence after the initial ablation. All 20 patients underwent preprocedural CE-MDCT. The Johns Hopkins Institutional Review Board approved the study protocol, and all subjects provided written informed consent. Follow-up entailed office visits at 3 and 6 months, as well as symptom-prompted electrocardiograms and Holter monitors.

Multislice computed tomography

CE-MDCT scans were performed with a commercially available 320-detector computed tomography (CT) scanner (Aquilion ONE, Toshiba Medical Systems, Otawara, Japan) on the same day or <1 week before the repeat AF ablation procedure. Slice collimation ranged from 320×0.5 mm, and tube voltage was 80, 100, or 120 kV, depending on the body habitus. Tube amperage ranged from 320 to 580 mA, depending on the body habitus and heart rate. Image acquisition was gated to 40% of the R-R interval during a breath-hold. β-Blockers were used at the discretion of the performing cardiologist to decrease the heart rate below 80 beats/min. The triphase contrast protocol includes a total volume of 60 mL (70 mL if body mass index >30 kg/m^2) of the noniodinated contrast material iopamidol (Isovue 370, Bracco Diagnostics, Princeton, NJ) administered at a rate of 5–6 mL/s in the following sequence: 20 mL saline test injection, 50 mL (100% contrast), 20 mL (50% saline, 50% contrast), and followed by 30 mL saline flush. The images acquired during the first pass were used for later segmentation and analysis.

Electroanatomic mapping

The repeat ablation procedure was performed at 21.6 ± 15.9 months after the initial ablation. All procedures were performed using a 3-dimensional (3-D) electroanatomic mapping system (CARTO 3, Biosense Webster Inc, Diamond Bar, CA). Detailed endocardium voltage maps of the LA were obtained with a 3.5-mm-tip, with 2-mm interelectrode spacing, irrigated ablation catheter (ThermoCool, Biosense Webster) during sinus rhythm. To optimize ablation success,[16] patients with persistent AF were referred for external cardioversion 3–4 weeks before CE-MDCT and AF ablation. Electrograms were filtered at 30–400 Hz (bipolar) and 1–240 Hz (unipolar). Myocardial regions were considered abnormal if the bipolar voltage was <0.5 mV and dense fibrosis if the bipolar voltage was <0.1 mV.[17–21] The CE-MDCT–derived images were registered to the electroanatomic map (EAM) by using standard landmark image registration techniques (Figure 1A). The mean distance between each EAM point and the closest CE-MDCT–derived chamber wall was calculated to evaluate registration accuracy. After the completion of electroanatomic mapping, a 20-electrode Lasso catheter was introduced into the LA. PV potentials were evaluated with the Lasso catheter, and reconnection sites were reisolated by using a wide circumferential approach. After ablation, patients were observed for 24 hours before discharge and were followed regularly at our outpatient clinic.

LA wall segmentation and graphical representations

The CE-MDCT–derived images were processed off-line using Seg3D software (version 2.1.4, University of Utah, Salt Lake City, UT). LA epicardial and endocardial borders were manually contoured on multiplanar axial images (Figure 1B). Care was taken in 2-D tracings of the endocardial and epicardial walls to confine the region of interest to only the LA wall and to avoid the blood pool and epicardial fat regions. The local mean LA wall attenuation measured in Hounsfield units (Hu) was obtained by using custom software written in MATLAB (MathWorks Inc, Natick, MA). The analysis software measures the geometric mean attenuation of 5-mm regions of the LA myocardium. For graphical representations (not statistical comparisons), the Otsu Threshold tool was used. The Otsu Threshold tool produces an image intensity histogram to allow the selection of histogram-based threshold levels. The threshold to display colors on the attenuation maps of Figure 2 (lower panels) was manually adjusted to highlight the lowest attenuation regions in red and the highest attenuation regions in purple, similar to the voltage maps (upper panels). The color bar at the right of each lower panel specifies the original CT data attenuation (in Hounsfield units).

Image and electrogram registration

Intra-atrial EAM points were registered to the 3-D CE-MDCT images by using a semiautomated, 3-step process. First, the pulmonary veins (PVs) were identified manually on the EAM and the image, and a similarity transform was applied to the EAM coordinates to minimize mean squared distance between the corresponding landmarks. Second, an iterative refinement to the similarity transform was used to minimize the mean squared distance between the EAM