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Original Article

# Acquisition of the pulmonary venous and left atrial anatomy with non-contrast-enhanced MRI for catheter ablation of atrial fibrillation: Usefulness of two-dimensional balanced steady-state free precession

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ABSTRACT

*Background:* Usually, the pulmonary venous and left atrial (PV–LA) anatomy is assessed with contrast-enhanced computed tomographic imaging for catheter ablation of atrial fibrillation (AF). A non-contrast-enhanced magnetic resonance (MR) imaging method has not been established. Three-dimensional balanced steady-state free precession (3D b-SSFP) sequences cannot visualize the PV–LA anatomy simultaneously because of the signal intensity defect of pulmonary veins. We compared two-dimensional (2D) b-SSFP sequences with 3D b-SSFP sequences in depicting the PV–LA anatomy with non-contrast-enhanced MR imaging for AF ablation.
*Methods:* Eleven healthy volunteers underwent non-contrast-enhanced MR imaging with 3D b-SSFP and 2D b-SSFP sequences. The MR images were reconstructed on the 3D PV–LA surface image. Two experienced radiological technicians independently scored the multiplanar reformatted (MPR) images on a scale of 1–4 (from 1, not visualized, to 4, excellent definition). The overall score was a sum of 5 segments (LA and 4 PVs).
*Results:* In the 2D b-SSFP method, MR imaging was successfully performed, and the 3D PV–LA surface image was precisely reconstructed in all healthy volunteers. The image score was significantly higher in the 2D b-SSFP method compared to the 3D b-SSFP method (19 [19; 20] vs. 12 [11; 15], $p=0.004$, for both observers). No PV signal intensity defects occurred in the 2D b-SSFP method.
*Conclusions:* The 2D b-SSFP sequence was more useful than the 3D b-SSFP sequence in adequately depicting the PV–LA anatomy.


## 1. Introduction

Catheter ablation of atrial fibrillation (AF) has been rapidly popularized by the appearance of three-dimensional (3D) mapping systems. Wide encircling isolation of the entire pulmonary vein (PV) antrum from the left atrial side provides the ability to eliminate AF trigger as well as treat the AF substrate. Complete isolation of the entire circle is considered the optimal electrophysiological end point. However, given the complex and highly variable individual 3D PV antrum anatomy, achievement of continuity and transmurality along the entire encircling ablation line is challenging. Hence, high-resolution images from magnetic resonance (MR) or computed tomographic (CT) imaging integrated with 3D mapping systems represent a highly desirable technique to maximize the efficacy and minimize the risks of AF ablation procedures [1–3].

Pulmonary venous and left atrial (PV–LA) anatomy is usually assessed with contrast-enhanced CT, because the non-contrast-

*Abbreviations:* AF, atrial fibrillation; 3D, three-dimensional; MR, magnetic resonance; CT, computed tomography; PV–LA, pulmonary venous and left atrial; b-SSFP, balanced steady-state free precession; MPR, multiplanar reformatted; LAA, left atrial appendage; LSPV, left superior pulmonary vein; TE, echo time; TR, repetition time; FA, flip angle; FOV, field of view; SENSE, sensitivity encoding

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enhanced MR imaging approach has not been well established [4]. Recently, examination using a 3D balanced steady-state free precession (b-SSFP) sequence has been reported (3D-B method) [5,6]. b-SSFP imaging techniques have progressed for evaluating the thoracic vasculature, including the coronary arteries and thoracic aorta, because of their inherent high signal-to-noise and contrast-to-noise ratios [7–9]. However, a PV signal intensity defect frequently occurs with practical use of the 3D-B method [10]. Actually, in cases of patients with renal failure, we must attempt the AF ablation and complete the procedure safely with compromising the image quality. The precise anatomical information of the LA antrum region and anterior ridge between the left atrial appendage (LAA) and left superior PV (LSPV) is necessary to achieve continuity of the ablation line. We assessed the feasibility of an MR imaging acquisition and processing protocol, a b-SSFP sequence without a contrast agent (2D-B method), to depict the accurate PV–LA anatomy for AF ablation.

## 2. Material and methods

### 2.1. Study subjects

The study population consisted of 11 healthy volunteers (11 men, 29.1 ± 6.1 years). This study was approved by the ethics committees of Himeji Cardiovascular Center (approval date, November 19, 2013; approval number, 20). A written informed consent to participate was obtained from all subjects. Every researchers involved in this study acted in conformity with the Declaration of Helsinki (adopted by the 18th WMA General Assembly, Helsinki, Finland).

### 2.2. MR imaging

All healthy volunteers underwent non-contrast-enhanced MR imaging with the 3D-B and 2D-B methods on a 1.5 T MR system (Intera Achieva; Phillips Medical Systems). The detailed scan parameters are summarized in Table 1.

#### 2.2.1. 3D-B method

The PV–LA anatomical images were acquired using a respiration-navigated, electrocardiogram-gated, 3D b-SSFP sequence in the transverse plane with the following parameters: 2.3-ms echo time (TE); 4.6-ms repetition time (TR); 80° flip angle (FA); 280 × 280-mm field of view (FOV); 256 × 256 scan matrix; 70 slices; 1.09 × 1.09 × 3-mm effective spatial resolution; and 0.55 × 0.55 × 1.5-mm reconstructed spatial resolution. To enhance the contrast between blood and the surrounding tissue, $T_2$-prep and fat saturation pre-pulse were applied. The navigator was placed over the dome of the right hemidiaphragm (gating window, 3.0 mm; tracking factor, 0.6). An acquisition window of approximately 150 ms using the multi-shot technique was placed at the mid-diastole. These techniques have been used to evaluate the coronary arteries. Scan parameters of the 3D-method are documented in a previous study [8,9]. The typical scan time for the 3D-B method was 7–15 min depending on the healthy volunteer heart rate and respiration pattern.

#### 2.2.2. 2D-B method

The PV–LA anatomical images were acquired using a respiration-navigated, electrocardiogram-gated, 2D b-SSFP sequence in the sagittal plane with the following parameters: 1.53 ms TE; 3.1 ms TR; 80° FA; 300 × 300 mm FOV; 192 × 192 scan matrix; 6.0 mm slice thickness; −3.0 mm gap; 40–60 slices; 1.56 × 1.56 mm effective spatial resolution; and 0.59 × 0.59 mm reconstructed spatial resolution. A parallel imaging technique, sensitivity encoding (SENSE), with a reduction factor of 3.0 was used to shorten the acquisition window. For the same reason, TE/TR, FOV, and scan matrix were determined. An acquisition window of approximately 200 ms using the single-shot technique was placed at the mid-diastole. The navigator was placed over the dome of the right hemidiaphragm (gating window, 3.0 mm; tracking factor, 0.6). The saturation bands were placed in the phase-encoding (anterior-posterior) line to minimize back-folding artifacts from the body walls. The typical scan time for the 2D-B method was 4–9 min depending on the healthy volunteer heart rate and

**Table 1**
MRI scan parameters.

| | 3D-B method | 2D-B method |
|---|---|---|
| Contrast medium | No | No |
| Scan mode | 3D | M2D |
| Scan technique | FFE | FFE |
| Contrast enhancement | Balanced | Balanced |
| Fast imaging mode | TFE | TFE |
| TFE shot mode | Multi-shot | Single-shot |
| Acquisition time | 146.7 ms | 202.1 ms |
| Profile order | Low_high (Radial) | Linear |
| Fat suppression | SPIR | No |
| Band width | 723.4 Hz | 964.5 Hz |
| $T_2$-prep (echo time/refocusing pulses) | Yes (50/4) | No |
| TR/TE/FA | 4.6 ms/2.3 ms/80° | 3.1 ms/1.53 ms/80° |
| FOV | 280 mm | 300 mm |
| Scan matrix (voxel or pixel size) | 256 × 256 (1.09 × 1.09 × 3.00 mm) | 192 × 192 (1.56 × 1.56 mm) |
| Reconstruction matrix (voxel or pixel size) | 512 × 512 (0.55 × 0.55 × 1.5 mm) | 512 × 512 (0.59 × 0.59 mm) |
| Slices | 70 | 40–60 |
| Slice thickness | 3.0 mm | 6.0 mm |
| Slice gap | – | −3.0 mm |
| Slice orientation | Transverse | Sagittal |
| Phase encoding direction | RL | AP |
| Slice scan order | – | Ascend |
| SENSE reduction factor | No | 3 |
| NEX | 1 | 3 |
| Cardiac synchronization (trigger delay/cardiac phase) | ECG-Trigger (user defined/mid-diastole) | ECG-Trigger (user defined/mid-diastole) |
| Navigator respiratory compensation | Gate and track | Gate and track |

FFE = fast field echo, TFE = turbo field echo, SPIR = spectral pre-saturation with inversion recovery spectrally selective inversion recovery, TR = repetition time, TE = echo time, FA = flip angle, FOV = field of view, NEX = number of excitations, SENSE = sensitivity encoding.