TECHNICAL NOTE

Fusion of Delayed-enhancement MR Imaging and Contrast-enhanced MR Angiography to Visualize Radiofrequency Ablation Scar on the Pulmonary Vein

Yutaka SHIGENAGA^{1*}, Kunihiko KIUCHI², Kazushi IKEUCHI¹, Takayuki IKEDA¹,
Katsunori OKAJIMA², Yoshinori YASAKA², and Hiroya KAWAI²

¹Department of Radiology, Himeji Cardiovascular Center
520 Kou, Saisho, Himeji, Hyogo 670–0981, Japan

²Department of Cardiology, Himeji Cardiovascular Center

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Delayed-enhancement magnetic resonance imaging (DE-MRI) is reported to detect the radiofrequency (RF) ablation scar of pulmonary vein isolation. However, the precise localization of RF scar is difficult to recognize due to the poor anatomical information of the 3-dimensionally reconstructed DE-MRI. We report 2 cases in which fusion of DE-MRI and contrast-enhanced MR angiography facilitated the identification of RF scar, and we detail our fusion method.

Keywords: *atrial fibrillation, catheter ablation, delayed enhancement, left atrium, magnetic resonance imaging*

Introduction

Pulmonary vein isolation (PVI) is a curative method for treating patients with drug-refractory atrial fibrillation (AF).¹ Recently, the visualization of radiofrequency (RF) scar by delayed-enhancement magnetic resonance imaging (DE-MRI) has been reported.^{2–4} However, the identification of areas of delayed enhancement is difficult in row MR images because of the thin left atrial wall (LA), so previous studies reported the need for specialized software for that identification.^{4,5} Unfortunately, even with the use of specialized software, the image quality of 3-dimensional (3D) DE-MRI visualization was insufficient to recognize the location of areas of delayed enhancement due to poor anatomical information.

We highlight a new 3D visualization method that fused DE-MRI and contrast-enhanced MR angiography (CE-MRA) using a commercially available workstation.

Methods

MR imaging

Contrast-enhanced imaging was acquired using a 1.5-tesla MR system (Intera Achiva; Philips Medical Systems, The Netherlands) equipped with a 32-channel cardiac coil. We first acquired CE-MRA for the morphological evaluation of the pulmonary vein (PV) and left atrium (LA), employing an expiratory breath-hold 3D T₁ turbo-field-echo (T₁-TFE) sequence without electrocardiogram (ECG) gating in the coronal plane during the first pass of a gadopentetate dimeglumine injection (Magnevist®; Bayer, Berlin, Germany) at a dose of 0.1 mmol per kilogram body weight. Typical scanning parameters were: repetition time (TR)/echo time (TE), 4.7/1.46 ms; voxel size, 1.37 × 1.37 × 3.00 mm (reconstructed to 0.68 × 0.68 × 1.50 mm); flip angle, 35°; sensitivity encoding (SENSE) with a reduction factor of 2 (phase direction) and 1.5 (slice direction); and 70 slices. Acquisition time was approximately 15 s. This is an established scan technique, and the acquired images have been used for AF ablation procedures.⁶

We then obtained DE-MRI with the following scan technique and parameters with reference to

*Corresponding author, Phone: +81-79-293-3131, Fax: +81-79-295-8199, E-mail: akashi-sodachi@yahoo.co.jp

previous studies.^{2–5,7–9} We used a 3D inversion recovery, respiration-navigated, ECG-gated, T₁-TFE sequence in the transverse plane to acquire DE-MRI 15 min after contrast injection. Typical scanning parameters were: TR/TE, 4.7/1.5 ms; voxel size, 1.25 × 1.26 × 2.60 mm (reconstructed to 0.63 × 0.63 × 1.30 mm); flip angle, 15°; inversion time (TI), 280 to 330 ms; SENSE with a reduction factor of 2; and 80 slices. The T₁ value was identified from myocardial T_{1null} using a Look-Locker method. The T₁ of the LA wall is similar to the left ventricular (LV) myocardial T₁.² Data acquisition was limited within 15% of the cardiac cycle. In sinus rhythm (SR) cases during MR scanning, data was acquired during the mid-diastolic phase of the LV. In AF cases during MR scanning, we set the shortest trigger delay of cardiac synchronization. Saturation bands were placed in the phase-encoding (right-left) line to minimize any back-folding from the arms. Fat saturation was used to suppress fat signals. Typical scan time for the DE-MRI study was 7 to 12 min depending on the patient's heart rate and respiration pattern.

Method of fusing images of DE-MRI and CE-MRA

Source images of the CE-MRA and DE-MRI were transferred to a workstation (AZE Virtual Place; AZE, Japan) and reconstructed as follows. 1) In data of the CE-MRA, we manually segmented the 3D PV-LA MRA image (3D-MRA) from the surrounding structures using the object extraction function and cut tool of the workstation (Fig. 1a–c). 2) In data of the DE-MRI, we segmented the PV-LA using its shape and position determined semi-automatically by the segmented 3D-MRA using the fusion software (Fig. 1c, d). 3) By masking manipulation, we created images of 2 different sizes—one enlarged approximately 3 pixels and the other reduced approximately 2 pixels (Fig. 2a–c). 4) We subtracted the reduced data from the enlarged data to calculate the LA wall (Fig. 2b–d). 5) We measured the intensity of contrast enhancement to quantify fibrosis. A voxel intensity histogram analysis of the LA wall defined an intensity threshold at one standard deviation (SD) above the mean value of the voxel intensity (Fig. 3a). Furthermore, we categorized the intensity of contrast enhancement using a color-coded scale (blue, < one SD; green, one to 2 SD; yellow, 2 to 3 SD; red, > 4 SD) (Fig. 3b). 6) We obtained a high quality 3D image with both anatomical and tissue information semiautomatically by fusing the 3D MRA and 3D DE-MRI using the multi-volume software (Fig. 3b–d). The reconstruction time was approximately 15 min.

Case presentation

We could visualize RF scar in 4 consecutive male patients (median age: 54 (53; 60) years) after ablation for paroxysmal atrial fibrillation (median LA diameter; 37 (36; 41) mm). All patients were in sinus rhythm during acquisition of MR imaging. The median heart rate was 65 (63; 67) beats per minutes. The median time to acquisition of MR imaging was 2 (1.5; 5) months after the first AF ablation.

Of the 4 cases, we present 2 representative cases who underwent catheter ablation for the treatment of drug-refractory paroxysmal atrial fibrillation. Figures 4 and 5 show the ablation sites using a 3D electroanatomical mapping (EAM) system (CARTO[®] 3 version 2.3, Biosense Webster, Inc., Diamond Bar, CA, USA; EnSite[™] NavX[™], St. Jude Medical, Inc., Saint Paul, MN, USA) and the fused 3D image. Most areas of delayed enhancement were consistent with the RF ablation tags from the EAM system except at the roof of the left superior pulmonary vein (LSPV) (Fig. 5).

Discussion

We demonstrated that the fusion of images of DE-MRI and CE-MRA using a commercially available workstation facilitated identification of areas of delayed enhancement. Previous studies that reported visualization of these areas^{4,5,7–9} suggested potential applications of DE-MRI for predicting the risk of stroke as well as AF recurrence after a procedure with PVI and reducing both procedure time and RF application time in repeated AF ablation procedures. Unfortunately, 3D visualization of the areas of delayed enhancement requires specialized software, so precise methods for the visualization are not fully established in clinical use. Our primary finding was that image quality for visualizing areas of delayed enhancement using our new method of fusing DE-MRI and CE-MRA improved owing to the precise anatomical information provided from the CE-MRA. In repeat AF ablation procedures, the operator must assess the electrophysiological findings to detect the RF scar gap (reconduction site). Ouyang and associates reported scar gaps (reconduction site) at the anterior ridge between the left PVs and left atrial appendage, the carina region between the LSPV and left inferior PV, and the roof at the enlarged antrum region in most cases.¹⁰ The anatomy in those areas is very complex but still very important. Technical limitations of DE-MRI prevented complete visualization of the precise anatomy because of the anatomical complexity of the PV and LA. Our method is superior to previous methods because data from the CE-

Fig. 1. The reconstruction procedure from the segmentation of the 3-dimensional (3D) pulmonary veins (PV) and left atrium (LA) in the data of contrast-enhanced magnetic resonance angiography (CE-MRA) to the reflection of the shape and position on the data of delayed-enhancement MR imaging (DE-MRI). (a) The visualized CE-MRA using a volume-rendering technique. (b) The segmented 3D-MRA image of the PV-LA from the surrounding structures. (c) The CE-MRA data in which masking processing was applied for outputting b. (d) The DE-MRI data in which the masking area of c was reflected.

Fig. 2. The reconstruction procedure of the extraction of the left atrial (LA) wall by masking manipulation. (a) Data of delayed-enhancement magnetic resonance imaging (DE-MRI) in which the shape and position of the LA was determined by reflecting the segmented 3-dimensional (3D) MR angiography (MRA). (b) The data was enlarged to 3 pixels to include the LA wall by the dilation function on the software. (c) The data was reduced to 2 pixels to exclude the LA wall by the erosion function on the software. (d) The data of the LA wall was calculated by subtracting c from b.

Fig. 3. The reconstruction procedure of the color rendering and fusion of the 3-dimensional (3D) magnetic resonance angiography (MRA) and 3D delayed-enhancement (DE) MR imaging. **(a)** The voxel intensity histogram analysis of the left atrium (LA) wall defined an intensity threshold at one standard deviation (SD) above the mean enhancement. Furthermore, the intensity of the contrast enhancement was categorized by a color-coded scale (blue, < one SD; green, one to 2 SD; yellow, 2 to 3 SD; red, > 4 SD) **(b)** Reconstructed 3D-DE-MRI image with tissue information. **(c)** Reconstructed 3D-MRA image with anatomical information. **(d)** Fused 3D image with anatomical and tissue information.

MRA allows visualization of the precise anatomy and the fusion facilitates the recognition of areas of delayed enhancement. On the other hand, our method carries the risk of misregistration. A problem with registration accuracy is often suggested with such a fusion technique. In this report, the CE-MRA was acquired with an expiratory breath-hold because the DE-MRI was acquired in the expiratory phase using a respiration navigator technique. This contrivance improves the accuracy of registration.

Akoum and colleagues reported a process for quantifying fibrosis of the LA wall using CORVIEW image processing software (MARREK, Inc., Park City, UT, USA).⁵ Segmentation of the LA wall required the manual tracing of the endocardial border and the LA-PV blood pool in each slice of the DE-MRI volume. Similarly, Bisbal's group reported manual delineation of the epicardial and endocardial borders on axial-plane slices using self-customized software (Tissue Characterization Tool Kit) based on MATLAB (The MathWorks, Natick, MA, USA).⁴ In contrast, our fusion method did not require manual tracing. An experienced technologist can accomplish the 3D-MRA segmentation and masking manipulation in approximately 10 min. We

considered the time to segment the LA wall in our fusion method acceptable.

In the cases presented, a discrepancy between the RF ablation tags and areas of delayed enhancement was demonstrated at the roof of the LSPV (Fig. 5). We attributed this discrepancy to the previous inadequate RF ablation. The force of contact at the roof of the LA was less than that in the other areas because of efforts to avoid fatal complication, including cardiac perforation.¹¹ Fortunately, 18 months after the single procedure with a PVI, this patient had experienced no recurrence of AF without the use of anti-arrhythmic drugs. If AF recurred, those gap sites assessed by the DE-MRI could be ablation targets. The reported recurrence rate of AF after catheter ablation is approximately 25%.¹² Therefore, the noninvasive identification of insufficient RF scar with our method is useful for predicting the PV-LA conduction sites and shortening the time of repeat procedures.⁴

Our study has some limitations. We detailed the method for 3D visualization to detect areas of delayed enhancement using our fusion method by presenting 2 cases without statistical comparison of image quality between the fusion and conven-

Fig. 4. A 67-year-old man who underwent catheter ablation for treatment of drug-refractory paroxysmal atrial fibrillation. This patient underwent magnetic resonance (MR) imaging 75 days after the first procedure with pulmonary vein isolation (PVI). During MR imaging, the heart was in sinus rhythm (SR; heart rate, 63 beats per minute). Upper panel: The ablation data on the CARTO[®] system (**a**, PA view; **c**, LAO view; **e**, RAO view). The red (30 watt), pink (20 watt), and yellow tags (success sites) indicate the ablation points. Lower panel: The fused 3-dimensional images (**b**, PA view; **d**, LAO view; **f**, RAO view). The areas of delayed enhancement were consistent with the ablation tags from the CARTO[®] system. PA = posterior-anterior, LAO = left anterior oblique, RAO = right anterior oblique.

Fig. 5. A 54-year-old man who underwent a catheter ablation for treatment of drug-refractory paroxysmal atrial fibrillation. This patient underwent magnetic resonance (MR) imaging 240 days after the first procedure with pulmonary vein isolation (PVI). During the MR imaging, the heart rhythm was in sinus rhythm (SR; heart rate, 60 beats per minute). Upper panel: The ablation data on the NavX[™] system (**a**, PA view; **c**, superior view). Lower panel: The fused 3-dimensional images (**b**, PA view; **d**, superior view). Most areas of delayed enhancement were consistent with the ablation tags from the NavX[™] system, but not at the roof of the left superior pulmonary vein (LSPV). The yellow arrow indicates placement of the radiofrequency (RF) applications without a gap at the roof of the LSPV. The red arrow indicates an RF scar gap at the roof of the LSPV. PA = posterior-anterior.

tional methods. In the cases, we attributed the discrepancy between RF ablation tags and areas of delayed enhancement to previous inadequate RF ablation. However, we cannot rule out the possibility that our visualizing method by using DE-MRI underestimated the ablated tissue. A prospective, randomized study is needed to confirm the superiority and detection capability of this new method. Nevertheless, we achieved superior image quality with our method compared to that in previous studies.

Conclusions

Our 3D visualization method using fused images of DE-MRI and CE-MRA facilitated the identification of areas of delayed enhancement and may reduce procedural complexity in repeat AF ablation procedures.

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