Correlation between functional electrical gaps identified by ultrahigh-density mapping and by late gadolinium enhancement cardiac magnetic resonance in repeat atrial fibrillation procedure

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Introduction
Late gadolinium enhancement cardiac magnetic resonance (LGE-CMR) images can reveal previous atrial scarring due to radiofrequency (RF) lesions from atrial fibrillation (AF) ablation.1-3 Discrepancies between the electrical gap identification in the LGE-CMR and in the electroanatomic voltage map obtained using a circular catheter inside pulmonary veins (PVs) have been observed.1,4 New mapping methods able to acquire thousands of electrograms in a few minutes can identify lesion gaps very precisely.5 We present a case report that establishes the correlation between the gaps observed on the LGE-CMR reconstruction and those identified by ultrahigh-density activation mapping.

Case report
A 60-year-old woman without structural heart disease had documented episodes of paroxysmal AF and a previous ablation procedure in 2015. Three months after the first intervention the patient underwent a 3 Tesla LGE-CMR study for fibrosis analysis. The DICOM LGE-sequence images were postprocessed and a 3-dimensional left atrium (LA) shell was obtained using ADAS software (Galgo Medical SL, Barcelona, Spain). Pixel signal intensities were normalized by blood pool to obtain a color-coded image intensity ratio map. Image intensity ratio thresholds between healthy tissue (pink), pathologic fibrosis (degraded blue to green), and dense scar (red) were obtained according to experimental values from a previous study.6 Magnetic resonance imaging (MRI) gaps were defined as segments around PV with discontinuities in the ablation line of the previous RF application. A single operator blinded to electroanatomical map data identified the MRI gaps in the LGE-CMR reconstructions. Operators were blinded to this information until the end of the procedure.

The patient was admitted in our center for a repeat AF ablation procedure, which was carried out under conscious sedation. Double transseptal puncture was performed to access the LA. Two catheters (Orion and IntellaNAV OI; Boston Scientific, Cambridge, Massachusetts) were progressed to the LA through SL1 sheaths (St Jude Medical Inc, St. Paul, Minnesota). Using Orion as the mapping catheter, an activation map of the LA was obtained in sinus rhythm. Mapping time was 15 minutes and 27 seconds and 314 beats were acquired, with a total of 5805 electrograms available. We defined as “functional gap” those sites with electrical reconnection of the veins, identified as narrow activation wavefronts entering the veins assessed in the ultrahigh-density activation map. In total, we identified 8 functional gaps around the PVs (Figure 1), 2 of them in the right superior PV, 2 in the right inferior PV, and 4 in a left common collector. Figure 2 shows the gap location around the right PV in the activation map. All gaps identified by ultrahigh-density activation mapping corresponded to MRI gaps. However, not all gaps identified in the LGE-CMR reconstruction corresponded to functional gaps detected by ultrahigh-density activation mapping. RF was applied in the functional gaps at the earliest activation site entering the PV. When every functional gap was blocked, any change inside the PV activation sequence could be observed (Figure 3). Thirteen RF applications, in all the functional gaps identified with the ultrahigh-density activation map, resulted in the isolation of all PVs. Total RF time was 430 seconds. No complications were observed during the procedure.

Discussion
The concordance observed in the present case between the functional gaps and the MRI gaps, identifying gaps in ablation lines as the target to guide the ablation procedure, is consistent with the results of several recent studies.6,7
In our report, no functional gap was identified in non-MRI gap sites, although extensive gaps were observed in the ablation lines around the left common collector. Functional gaps were only present in some discrete parts of these wide MRI gaps, suggesting that MRI gaps have a low positive predictive value for functional gap detection. In contrast, the absence of an MRI gap would have a very high negative predictive value for functional gap detection.

Another recent study observed a weak inverse point-by-point relationship between bipolar endocardial voltage maps and signal intensity in CMR.\(^4\) In our opinion, current bipolar voltage mapping methods are not sufficiently accurate to identify the local voltage around the reconnected veins (noise, lack of contact, low density of points, far-field of nearby areas, etc). Using a standard circular catheter inside the PV can fail to identify the exact location of the gap, as the dipole with the earliest activation time may not be located exactly at the functional gap site, depending on the progression of the catheter inside the PV. Discrepancies can be explained by a lack of continuity around the PV perimeter of the myocardium fibers that connect the LA and PV.\(^7\) Another source of discrepancy could be that the activation of these myocardial bundles inside the PV may not follow a straight vector, as was observed in an anatomic study.\(^8\) The new mapping tool used in the present case, with ultrahigh-resolution activation mapping, may lead to a more accurate identification of the functional gap site between the atrium and the PV.

Additional analysis of the correlation between functional gaps and MRI gaps may improve accuracy in identifying functional gaps at the moment of ablation and those that are not or not yet functional at the moment of the re-do procedure,\(^9,10\) and will also noninvasively obtain the positive predictive value and the negative predictive value of the LGE-CMR reconstructions in identifying functional gaps in the MRI gaps around PVs.

**KEY TEACHING POINTS**

- The application in atrial fibrillation re-ablation procedures of new ultrahigh-density mapping methods, able to acquire thousands of electrograms in a few minutes, helps to identify lesion gaps very precisely.
- Discontinuities of atrial scar induced by catheter in ablation lines could be detected by late gadolinium enhancement cardiac magnetic resonance (LGE-CMR).
- This case shows a good concordance between the functional gaps identified by ultrahigh-density mapping of the ostium around pulmonary veins and the anatomic gaps found in LGE-CMR.

Figure 1  Correlation between gaps identified by ultrahigh-density mapping and scar tissue from a previous late gadolinium enhancement cardiac magnetic resonance (LGE-CMR) study. Each star marks the location of 1 gap identified on the electroanatomic map. Continuous lines show a complete previous lesion in LGE-CMR reconstruction. Dotted lines show healthy tissue around the pulmonary vein perimeter. Note that stars are present only in the dotted line segments.

LAA = left atrial appendage; LCC = left common collector; RIPV = right inferior pulmonary vein; RSPV = right superior pulmonary vein.
Figure 2  
A: Example of functional gaps identified by ultrahigh-density mapping and their correlation with the left atrium (LA) shell derived from late gadolinium enhancement cardiac magnetic resonance (LGE-CMR). Left superior, right superior, and left inferior panels show the activation map in sinus rhythm where the functional gaps A1, A2, and A3, respectively, are identified in the septal part of the right pulmonary vein perimeter. All gaps correspond to healthy tissue in the LA shell (A4). White arrows show the propagation direction in each functional gap. All panels show the same modified right anterior oblique view. 
B: False-positive gap detected in the LA shell derived from LGE-CMR. In this case a conduction block line (double potentials) could be observed along the previous ablation line (B1, B2, and B3). However, a gap is observed in the magnetic resonance imaging reconstruction (B4). All panels show the same modified posterior-anterior view. RIPV = right inferior pulmonary vein.
Conclusions

This case report shows that every functional gap assessed by ultrahigh-density activation mapping matched with an MRI gap. On the other side, no functional gap was present in the absence of an MRI gap, suggesting a high negative predictive value.

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