Heterogeneous scar with functional block in ventricular tachycardia circuit: Visualization of moderate high-density mapping

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Introduction

In this paper, we propose a novel method of voltage-map reconstruction using the Advisor™ HD Grid (Abbott Laboratories, Abbott Park, IL) to elucidate the 3-dimensional anatomical and electrophysiological substrates. High-density mapping makes it possible to clarify the activation pattern during ventricular tachycardia and a substrate during sinus rhythm on the endocardial surface. To enhance the mapping resolution, the use of catheters with smaller electrodes and closer interelectrode spacing can be used.[1] In contrast, the unipolar or bipolar with wider interelectrode can be a clue for estimating the substrate in 3 dimensions because of far-field potential sensing.[2,3] In this case report, we describe the successful identification of a heterogeneous scar within a dense scar with the use of a reconstructed voltage map with wider interelectrode spacing and suggest the involvement of the heterogeneous scar in the mechanism of functional block.

KEY TEACHING POINTS

- Voltage-map reconstruction with wide interelectrode space using the HD Grid (Abbott Laboratories, Abbott Park, IL) allows for clear visualization of the heterogeneous scar within transmural infarct regions.
- The functional block that appears at the border of the heterogeneous scar is consistent with the source-sink mismatch theory.
- The identification of isolated heterogeneous scars might lead to the prediction of the location of functional blocks during sinus rhythm.

Case report

A 75-year-old man with an implantable cardioverter-defibrillator for ventricular tachycardia associated with an old myocardial infarction presented to the emergency department with palpitations and shocks from his implantable cardioverter-defibrillator. Wide QRS tachycardia with a right bundle branch block morphology and inferior axis with I-lead negative and atrioventricular dissociation were shown on 12-lead electrocardiogram, resulting in a diagnosis of ventricular tachycardia. Transthoracic echocardiography and computed tomography revealed thinning of the anterior wall. The patient was immediately hospitalized, and because of drug treatment resistance and frequent implantable cardioverter-defibrillator shocks, we decided to perform catheter ablation. Using the HD Grid, we delineated a voltage map of the left ventricle during sinus rhythm. When the scar was set to <0.5 mV, we observed a huge scar from the anterior wall to the apex. The setting was changed to <0.1 mV as scar and 0.1–0.5 mV as the low-voltage area (Figure 1A). On the activation map during sinus rhythm, we found the wavefront from the apex spread onto the anterior wall without block (Supplemental Video 1) and fixed block lines, as shown in Figure 2A. Clinical ventricular tachycardia with inferior axis and right bundle branch block morphology was easily induced, and we delineated a full-activation map during ventricular tachycardia (Supplemental Video 2). The block lines appeared as shown in Figure 2B, and the entrance was formed between 2 lines. We identified the isthmus in the anterior mid area and detected the exit in a healthy region at the base of the anterior wall. We achieved concealed entrainment at the site of the entrance side in the isthmus, and the postpacing interval matched the cycle length of ventricular tachycardia. Ventricular tachycardia was terminated in 7.3

KEYWORDS Catheter ablation; Dense scar; Functional block; Heterogeneous scar; Interelectrode spacing; Ventricular tachycardia; Voltage mapping; Wall thickness
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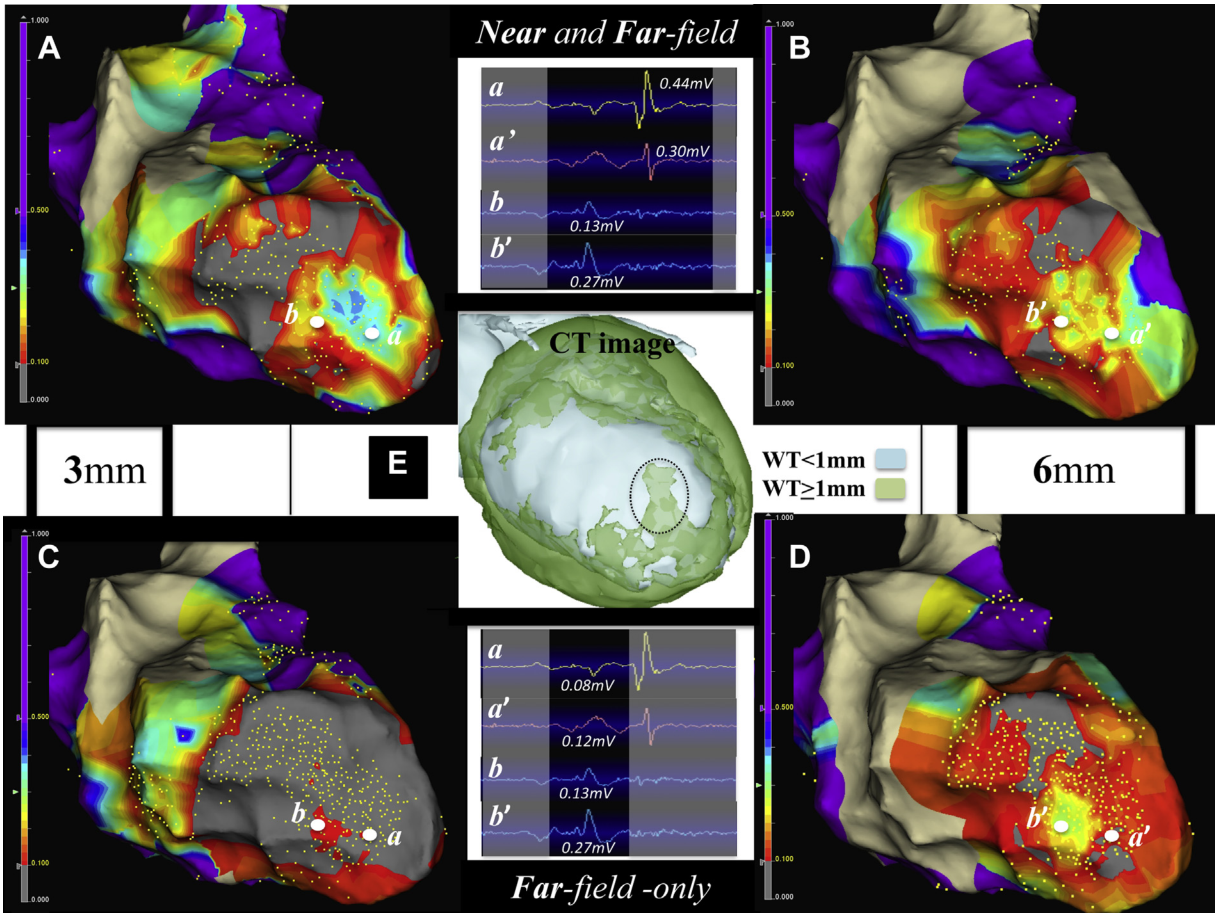

Figure 1 Voltage maps for 3-mm (**A, C**) and 6-mm (**B, D**) interelectrode spacing, with voltage amplitudes of ≤0.1 mV shown in gray, ≥0.5 mV shown in purple, and 0.1–0.5 mV shown in red, yellow, green, and blue. Points *a* and *b* on the 3-mm interelectrode spacing map correspond to points *a'* and *b'* on the 6-mm interelectrode spacing map. In A and B, the voltage amplitude is measured automatically in peak-to-peak mode, whereas in C and D, the amplitude of the far-field potential (excluding the near-field potential) is measured manually. Additionally, **E** presents a 3-dimensional computed tomography image imported into the EnSite system (Abbott Laboratories, Abbott Park, IL). Light blue indicates the endocardial surface detected in contrast-enhanced computed tomography, and light green indicates the space between the endocardial and epicardial surfaces, ie, the myocardium. The unclear myocardial area depicts the thinnest wall (<1 mm). CT = computed tomography; WT = wall thickness.

seconds by ablation with 35 watts and 17 mL/h of irrigation to the site. Subsequently, any ventricular tachycardias were no longer inducible.

We reconstructed the voltage map using interelectrode spacing of 3 and 6 mm, distinguishing far-field from near-field potentials (Figure 1A–D). As a result, on the 3-mm interelectrode spacing and far-field-only map (Figure 1C), we observed extensive scar regions with voltages less than 0.1 mV. On the 6-mm interelectrode spacing and far-field-only map (Figure 1D), the overall voltage amplitude in the scar increased slightly, mostly from 0.1 to 0.2 mV (red) or to <0.1 mV (gray), but isolated areas of relatively high voltages >0.2 mV (yellow-green) appeared. We defined the gray and red zones as dense scar and the yellow-green zone as isolated heterogeneous scar, as shown in Figure 1D. On the computed tomography image shown in Figure 1E, the region representing wall thickness showed heterogeneity, indicating an isolated heterogeneous scar, with an average wall thickness of approximately 2.0 mm (black dashed line in Figure1E) . The voltage gap, which is the dividing line between the isolated heterogeneous scar and dense scar, was aligned perfectly with the functional block line (red arrow in Figure 2C). The successful ablation site was located within the isolated heterogeneous scar (green dot in Figure 2C). Mean voltages in the isolated heterogeneous scar and dense scar were 0.23 ± 0.04 and 0.12 ± 0.03 mV, respectively. The difference in voltage amplitude between isolated heterogeneous scar and dense scar was clearly larger on the 6-mm interelectrode map (Figure 3).

Discussion

Main findings

This case report provides the following new insights. (1) Voltage-map reconstruction using widely spaced interelectrode is useful for identifying an arrhythmogenic heterogeneous scar within transmural infarcts. (2) The functional block line, which developed at the border of the heterogeneous scar, formed the entrance of the ventricular tachycardia circuit.

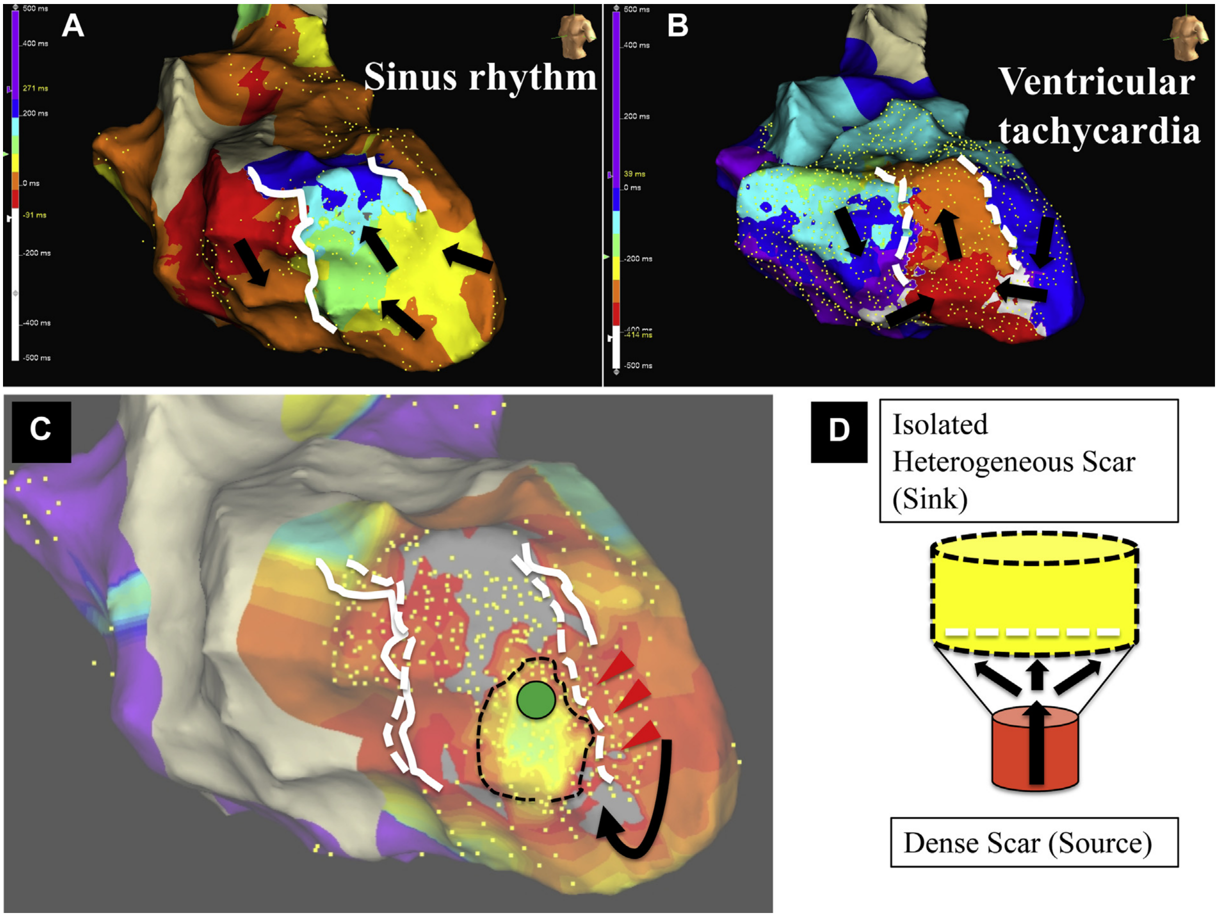

Figure 2 Block lines in this case and their etiology. **A:** Reconstructed isochronal late activation map in sinus rhythm with 8 colors; discontinuous color boundaries are shown as fixed block lines (*solid white lines*). **B:** Activation map during ventricular tachycardia with discontinuous color boundaries shown as block lines (*dashed white lines*). **C:** Block lines during sinus rhythm and ventricular tachycardia are superimposed on the 6-mm interelectrode spacing and far-field map. The red arrow indicates the functional block line during only ventricular tachycardia. The area surrounded by black dotted lines indicates the isolated heterogeneous scar. The green dot indicates the successful ablation site, and the curved long arrow with solid black line indicates the rotating wavefront produced by the functional block. **D:** Schematic diagram of how the functional block was formed in this case using the source-sink mismatch model. Dense scar is shown as the source, and isolated heterogeneous scar is shown as the sink. The white dashed functional block line developed when the wavefront propagates in the direction of the black arrow.

Objectives and methods of voltage-map reconstruction

The reconstruction aimed to project the 3-dimensional structure of the scar onto a 2-dimensional map. In ischemic scars, the surviving myocardium is reflected in wall thickness and correlates with voltage amplitude.[4,5]

First, voltage maps were created for 3-mm and 6-mm interelectrode spacing. The use of catheters with smaller electrodes and closer interelectrode spacing can enhance the mapping resolution.[1] In contrast, because of far-field potential sensing, the unipolar or bipolar with wider interelectrode spacing can be a clue for estimating the substrate in three dimensions.[2,3] Typically, a wider interelectrode spacing indicates a higher voltage amplitude; the reason is that the mid-myocardium and epicardium have relatively more far-field potentials.[3,5]

Second, we manually distinguished between far-field ventricular electrograms and near-field signals such as local abnormal ventricular activities and late potentials. According to a report on the correlation between voltage amplitude and wall thickness measured by computed tomography, wall thickness strongly correlated with far-field-only voltage maps but weakly correlated with the voltages collected by automatic peak-to-peak annotation. This outcome resulted from inconsistency on whether automatic annotations should be on near- or far-field potentials. In the thinnest scars, such annotation issues could be attributed to the absence of a far-field signal derived from the substrate in 3 dimensions and the relative near-field signal's high values.[6]

Thus, to assess the myocardial wall thickness in the scar area, we reconstructed the voltage map using only far-field potentials and by widening the interelectrode spacing from 3 to 6 mm (Figure 1D). As expected, Figure 1D best reflects the myocardial wall thickness.

Results of voltage-map reconstruction

On the 3-mm interelectrode spacing and far-field-only map (Figure 1C), most of the area was recognized as scar

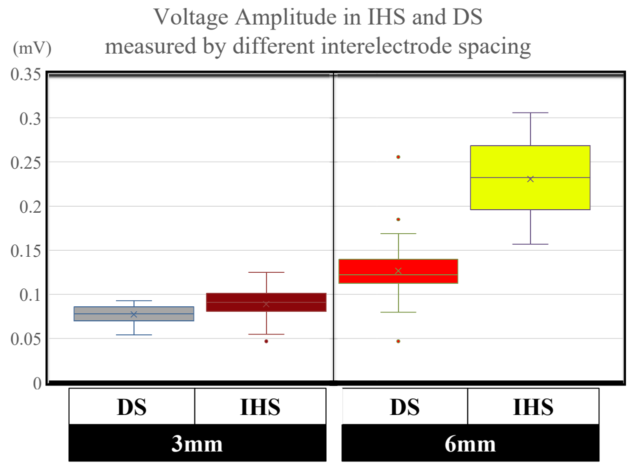

Figure 3 Graph comparing the voltage amplitude between 3-mm and 6-mm interelectrode spacing in isolated heterogeneous scar and dense scar. DS = dense scar; IHS = isolated heterogeneous scar.

at <0.1 mV. On the 6-mm interelectrode spacing and far-field-only map (Figure 1D), the scar area was divided into isolated heterogeneous scar and dense scar. Figure 3 shows that the voltage amplitude of the isolated heterogeneous scar was obviously greater than the corresponding area of the 3-mm interelectrode spacing map, suggesting that the wall thickness in isolated heterogeneous scar is maintained as compared with the surrounding area (which is termed the *dense scar*). In the dense scar, where the voltage amplitude did not increase sufficiently as the interelectrode spacing was widened, can be considered to have no deep residual electrical myocardium (ie, the thinnest myocardium). Furthermore, the difference in voltage amplitude between the isolated heterogeneous scar and dense scar was clearly larger on the 6-mm interelectrode map than on the 3-mm map. This indicates that by widening the interelectrode spacing to 6 mm, we have successfully visualized the arrhythmogenic isolated heterogeneous scar. In transmural infarction, heterogeneous scar has been reported to be a causative substrate for ventricular tachycardia in magnetic resonance imaging evaluations.[7,8] However, no reports have performed a wide bipolar voltage-mapping evaluation.

Voltage gap–matched functional block line

The border of the isolated heterogeneous scar and dense scar, or the voltage gap, coincided with the functional block line in this case (Figure 2C). The functional block is one of the factors that form the ventricular tachycardia circuit[9,10] and is defined as a conduction block that occurs only during tachycardia, not during sinus rhythm or pacing. It can also appear as a line of apparent block or as slow activation.[11] In contrast, the fixed block line is a line of block that can be found in both sinus rhythm and tachycardia. In this case, the fixed block line is considered to be the portion of the dense scar where there is no pathologically excitable myocardium, whereas the functional block line was suggested to develop at the border of the isolated heterogeneous scar, where the myocardium was relatively preserved.

These results are consistent with the theory of source-sink mismatch. Functional block can develop because of source-sink mismatch, when there is a sharp change from thin tissue to thicker viable tissue perpendicularly at the boundary[12,13] (Figure 2D). In this case, the functional block line was developed at the border from the dense scar to the isolated heterogeneous scar in the direction of blocking the wavefront from the lateral apex to the anterior septum. A wavefront that curves around and enters the entrance was noted at the lower end of the functional block line (curved long arrow with solid black line shown in Figure 2C). Although we did not investigate the difference between the complete block line and the conduction delay, it may be related to the rotation of the wavefront entering the isolated heterogeneous scar at the edge of the functional block line.

Acquisition of electric potentials by the HD Grid

All recorded voltages are subject to the size, spacing, and orientation of the recording electrodes relative to the wavefront.[14] The Advisor HD Grid consists of 4 parallel splines that are equally spaced 3 mm apart, each with 4 1-mm electrodes spaced 3 mm apart (4×4 electrode configuration). The catheter design allows for the simultaneous recording of bipolar electrograms in the orthogonal direction and within the same dimension. The best duplicate algorithm, a feature that automatically selects the highest voltage, minimizes the effect of differences in wavefront direction on the voltage amplitude.[15]

Future work

To determine whether this voltage-map reconstruction using widely spaced interelectrode space is effective in other cases, more cases must be accumulated. Simultaneous endocardial and epicardial mapping as well as magnetic resonance imaging should be used to evaluate the validity of scar assessment. Future studies should also address the appropriate interelectrode spacing resulting from differences in myocardial wall thickness in each case.

Conclusion

We visualized the entire endocardial ventricular tachycardia circuit using high-density mapping with narrowly interelectrode space and the arrhythmogenic heterogeneous scar by moderate high-density mapping using a widely spaced interelectrode. The heterogeneous scar was considered to be a factor related to the appearance of functional block.

Appendix

Supplementary data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrcr.2021.06.014.

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