A case of a low-displacement area on four-dimensional computed tomography corresponding to a low-voltage area on the voltage map

Akinori Matsumoto, MD, PhD,* Ryo Ogawa, RT,† Masafumi Maeda, RT,† Shusuke Shimozawa, RT,† Aya Inakami, RT, AHS,† Tomoyuki Tomikawa, RT†

From the *Department of Cardiovascular Internal Medicine, Akashi Medical Center, Hyogo, Japan, and †Department of Radiology, Akashi Medical Center, Hyogo, Japan.

Introduction
Recently, 4-dimensional computed tomography (4DCT) has become available for the preoperative planning of transcatheter aortic valve intervention.1 The 4DCT is reconstructed at 10% increments over the cardiac cycle, so that the 4DCT can evaluate not only the displacement of perivalvular structures but also the displacement of the myocardium.2

Most premature ventricular contractions (PVCs) arise from normal hearts. Further, it has been reported that PVCs arise from low-voltage areas and/or scar areas observed on voltage maps during electrophysiological studies, despite a structurally normal heart.3,4 Further, it has also been reported that a heterogeneous distribution of collagen within an infarct and the subendocardial layer is consistent with voltage mapping.5 From the above, we considered that an impaired myocardium would be displayed as having low dynamics on the 4DCT, whereas it would be displayed as a low-voltage or scar region on the voltage map.

We herein describe our case, in which catheter ablation of PVCs was successfully performed, and a low-displacement area on the 4DCT corresponded to a low-voltage region on the voltage map.

Case report
Patient and history
A 75-year-old man with PVCs in whom pharmacologic therapy was ineffective was referred to our hospital for catheter ablation. He had severe chest discomfort and palpitations. Frequent PVCs (21,447/80,286 beats; 26.6% [PVC/total heart beats]) were demonstrated on 24-hour Holter monitoring. The PVCs documented on the 12-lead electrocardiogram were suspected to originate from around the posteroseptal region of the left ventricle. He had no family history and a normal left ventricular (LV) contraction.

4DCT imaging
Multidetector CT (MDCT) was conducted before the ablation procedure. The MDCT was performed with a 128-detector CT scanner (Brilliance 64; Philips, Best, The Netherlands) using an axial gating protocol. A beta-blocker was administrated to the patient to conduct the MDCT under sinus rhythm. The reconstruction slice of the MDCT was 0.8 mm and the reconstruction interval was 0.8 mm at our hospital. On the 4DCT, the dynamic data obtained by MDCT with 18 equally spaced reconstructions during 10 phases during the electrocardiographic synchronization was complemented by 30 phases using PhyZiodynamics (PhyZiodynamics, 4D motion analysis; Ziosoft Inc, Tokyo, Japan), and then a 4D motion analysis was performed. In brief, the 4DCT image was reconstructed from the raw data obtained by the MDCT using a 4D motion analysis after the CT scan. In the 4D motion analysis, the reference time phase was set to the R on the electrocardiogram. The mechanism of the

KEY TEACHING POINTS
- Four-dimensional computed tomography (4DCT) is a new modality that can visually evaluate the cardiac motion.
- The 4DCT image was reconstructed from the raw data obtained by multidetector computed tomography using a 4D motion analysis. That is why there was little damage to the patient.
- The low-displacement area over the cardiac cycle indicates a decrease in the normal myocardium.
- The low-displacement area on the 4DCT correlates to the low-voltage area on the voltage map.
4DCT was to measure the displacement where the voxel of the myocardium had moved and to color it automatically according to the displacement. In patients with myocardial infarctions, the myocardium was necrotized because of an occlusion of the coronary artery. In most cases, that area displayed a low-voltage area because the normal myocardium was decreased. In brief, it was thought that the area where the myocardium did not move was an area where the residual myocardium had decreased. On the basis of this concept, we thought that the low-displacement area on the 4DCT indicated a site with a small amount of myocardium and that it exhibited a low-voltage area. The colors were set with red displayed as an area with high dynamics with a distance moved of more than 3 mm throughout the cardiac cycle, and the other colors were set as areas with low dynamics with a distance moved of less than 3 mm throughout the cardiac cycle on the color map (orange to indigo, the range of progressively lower-displacement areas [less than 3 mm], and gray, the low-displacement areas). The setting of the red color could be changed to 2 mm, 3 mm, 5 mm, or 10 mm after the 4D motion analysis has been conducted. We chose an initial color setting that was set to be a red color when moving a distance of more than 3 mm. That was because in another study we observed that a voltage amplitude of less than 1.5 mV on the voltage map was related to a displacement of less than 3 mm on the 4DCT. In this case, the low-displacement area was distributed over the posteroseptal region and posterior papillary muscle (Figure 1).

Electrophysiological study and catheter ablation procedure

The ablation procedure was guided by a 3D mapping system (EnSite NavX; St. Jude Medical, Minneapolis, MN). A coronary sinus catheter (BeeAT; Japan Lifeline, Tokyo, Japan) was positioned in the distal great cardiac vein and a right ventricular catheter (Fe-po; Fukuda Denshi, Tokyo, Japan) in the right ventricular apex. As a mapping catheter, a multielectrode catheter (HD grid; St. Jude Medical, Minneapolis, MN) was used via a transaortic approach. A voltage map was created using a multielectrode catheter (voltage criteria: normal voltage, >1.5 mV; low-voltage area, 0.5–1.5 mV; scar area, <0.5 mV) (Figure 2). The low-voltage area was distributed over the posteroseptal area and posterior papillary muscle, the same as the low-displacement area observed on the 4DCT. The low-displacement area on the 4DCT corresponded to the low-voltage area on the voltage map (Figures 1 and 2).

The earliest activation site was in the posteroseptal region on the activation map. We ablated the earliest activation site with an irrigation catheter (FlexAbility; St. Jude Medical, Minneapolis, MN) via a transaortic approach. The settings used during the ablation procedure are described as follows: output, 30–35 watts; thermo-limiter, 43°C; and irrigation flow, 8–15 mL/min. The clinical PVC disappeared within 6 seconds after starting the first application. Then, we ablated around the earliest activation site with several additional points (Figure 3). The endpoint was the noninducibility of any clinical PVCs with pharmacologic and/or electrical stimulation. During a follow-up of 6 months, the patient has not experienced any further palpitations and has had no documented PVCs.

Discussion

In recent years, among the patients with ventricular arrhythmias undergoing catheter ablation, it has been reported that ventricular tissue fibrosis estimated by delayed-enhanced magnetic resonance imaging has been independently associated with the likelihood of recurrent arrhythmias. Although cardiac magnetic resonance (CMR) imaging has a comparatively higher temporal resolution, it has a poorer spatial resolution for the CMR images; that is, it is usually limited to about a 2 mm plane, with a 6–8 mm thickness, so the CMR image usually scans only 1–5 slices.

The MDCT has not only a higher temporal resolution but also a higher spatial resolution than CMR. Moreover, in a recent study, MDCT was reported to also be useful for a detailed assessment of scar regions. However, MDCT is associated with a lower contrast-to-noise ratio within
myocardial tissue, and therefore MDCT is inferior to delayed-enhanced CMR for an assessment of the scar characterization. Therefore, if CMR is unavailable, MDCT could be used as an alternative tool for a detailed assessment of the myocardial structure and function\textsuperscript{10}; however, MDCT plays a relatively small role as a diagnostic tool in patients with ventricular arrhythmias as compared to CMR.

Compared with the 2 above modalities, 4DCT is reported to be useful for evaluating not only the preoperative planning for transcatheter aortic valve interventions, but also the regional cardiac function after a transplantation of a skeletal myoblast sheet\textsuperscript{2}, because 4DCT can evaluate the displacement of the myocardium. Similar to the evaluation of myocardial infarctions by echocardiography, a low-displacement area of the myocardium could estimate a scar region and a high-displacement area of the myocardium could estimate a normal heart area in the 4DCT.

Further, the reason that idiopathic PVCs with a normal LV function demonstrated a low displacement can be described as follows. In general, idiopathic PVCs/ventricular tachycardias do not exist in low-voltage and/or scar areas. However, a previous study\textsuperscript{3} reported that a low-voltage area exists in the case of idiopathic PVCs from the right ventricular outflow tract and that idiopathic PVCs from the right ventricular outflow tract originate from low-voltage or transitional areas. In that study, the authors suggested that it is necessary to beware of that and to discriminate it from arrhythmogenic right ventricular cardiomyopathy.

![Image](image1.png)

**Figure 2** The voltage map and activation map of the earliest activation site and ablation sites. The purple area indicates the normal-voltage area, and areas from indigo to orange indicate low-voltage areas. The low-voltage area was distributed over the posteroseptal region and posterior papillary muscle. Voltage criteria: normal voltage, $>1.5$ mV; low-voltage area, $0.5$–$1.5$ mV; and scar area, $<0.5$ mV. A: Caudal 70°. B: Anteroposterior (AP) view. The earliest activation site was in the posteroseptal region on the activation map. The first application is shown as the blue tag and the additional applications as red tags. The clinical premature ventricular contraction disappeared during the first application. C: Caudal 70° view. D: AP view.

![Image](image2.png)

**Figure 3** Pre- and postprocedural electrocardiograms (ECGs) and the electrograms at the site of the ablation target. A: Preprocedural ECG. B: Postprocedural ECG. C: Electrogram at the site of the ablation target. The distal electrode recording preceded the beginning of the QRS complex by 40 ms in lead II. A QS pattern was exhibited in the unipolar electrogram. The voltage amplitude was $0.479$ mV at the site of the ablation target during sinus rhythm. D: The effect of the application. The premature ventricular contraction disappeared within 11 seconds after starting the ablation application.
Another study reported that a case that had been considered to be attributable to idiopathic PVCs proved to be caused by cardiac sarcoidosis 16 years after the first diagnosis of PVCs. Although there was no low-voltage or scar area at the time of the first diagnosis in that case, the low-voltage and scar areas developed along with the progression of the cardiac sarcoidosis over 16 years. The low-voltage and scar areas attributable to cardiac sarcoidosis tend to be patchy and spotty because of inflammation from sarcoidosis. The pattern and location of the involvement also varies widely. Any segment of the left or right ventricle and any layer of the myocardium may be affected by cardiac sarcoidosis,.

In our case, although we could not evaluate the pathology of the cardiac sarcoidosis because no biopsy was performed, we considered that we may have encountered the course of the cardiac sarcoidosis as described above. For that reason, we considered that the low-voltage area was distributed within the LV inferoseptal region and that the PVCs originated from that low-voltage area. Therefore, we believe that hereafter we need to be aware of whether or not the LV motion is impaired.

Moreover, although the LV function is ordinarily assessed by echocardiography, echocardiography is a user-dependent modality and the imaging has a poor reproducibility as compared to CT or magnetic resonance imaging. Even if the LV wall motion is almost normal as assessed by echocardiography, the LV function may be becoming impaired. For that reason, we considered that even in cases with idiopathic PVCs and a normal LV, a low-displacement area may exist.

In this study, we experienced a case in which the low-displacement area observed on 4DCT corresponded to the low-voltage area observed on the voltage map. Further study is needed to confirm the potential of 4DCT to replace the voltage map. The incremental information obtained from this approach was that it may be possible to reduce the procedure time, and ultimately may be possible to reduce adverse events by determining the low voltage area before the procedure.

Conclusions
To the best of our knowledge, this was the first report to show that the low-displacement area observed on the 4DCT obtained before the procedure corresponded to the low-voltage area observed on the voltage map obtained during the ablation procedure. The 4DCT may be more useful for planning the ablation strategy than the voltage map.

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