Usefulness of omnipolar electrograms to uncover P1 potentials during left posterior fascicular ventricular tachycardia

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Introduction

Left posterior fascicular ventricular tachycardia (LPFVT) is a macroreentrant tachycardia that uses the Purkinje fiber network as a component of its circuit. The antegrade limb of the circuit is composed of mid- to late-diastolic Purkinje potentials (P1), whereas the retrograde limb is formed by the left ventricular septal myocardium.[1] Although electroanatomic mapping and the identification of the critical Purkinje potentials are essential for the successful ablation of the LPFVT,[1–3] the P1 potentials are sometimes unrecordable even with the use of multielectrode catheters with small electrodes and close spacing. These unrecordable P1 potentials are observed in approximately 20%–30% of LPFVT cases[1,2] and present a challenge for the attending physicians. In this report, we present a successful case of P1 potential mapping during an LPFVT using the Advisor™ HD Grid catheter and Omnipolar Technology (OT) (both Abbott, St Paul, MN). The HD Grid catheter is designed with a regular 4 × 4 square lattice, featuring 1-mm-long electrodes that are spaced 3 mm apart. It allows bipolar recording along and across the splines. The bipolar and omnipolar electrocardiograms obtained from the HD Grid catheter indicated that the directional dependence of bipolar recordings significantly contributes to the unrecordable P1 potentials.

KEY TEACHING POINTS

- Electroanatomic mapping and identification of mid- to late-diastolic Purkinje potentials (P1) are critical to achieve successful ablation of left posterior fascicular ventricular tachycardia (LPFVT). However, the P1 potentials are sometimes unrecordable even with the use of multielectrode catheters equipped with small electrodes and close spacing.
- Directional dependence of bipolar electrograms is one of the causes of unrecordable P1 potentials. The Advisor HD Grid catheter and Omnipolar Technology (both Abbott, St Paul, MN) help uncover the P1 potentials during LPFVT.
- Despite using the latest 3-dimensional mapping system, automated annotation of the P1 potentials remains challenging, likely owing to their low-frequency and low-amplitude nature.

Case report

A 41-year-old man presented to the emergency department with palpitations. Twelve-lead electrocardiography revealed a regular tachycardia with a wide QRS complex and a ventricular rate of 198 beats per minute. The QRS morphology indicated a right bundle branch block with left axis deviation (Figure 1A). The chest radiograph and echocardiographic examination revealed no abnormalities. An intravenous administration of 1.25 mg verapamil terminated the tachycardia. The patient was diagnosed with LPFVT. Two months later, the patient returned to the hospital with a recurrent tachycardia. After obtaining informed consent, we performed catheter ablation of the LPFVT.

An electrophysiological study was performed without sedation, and all antiarrhythmic drugs were discontinued for a duration of more than 5 half-lives before the study. A 5F decapolar catheter was positioned in the coronary sinus, another in the His bundle, and a 5F quadripolar catheter was positioned in the right ventricular apex. Tachycardia was induced by atrial pacing, and the occurrence of atrioventricular dissociation during the tachycardia confirmed the diagnosis of ventricular tachycardia. Overdrive pacing from the right ventricle exhibited constant and progressive fusion. The His-ventricular interval during sinus rhythm and the

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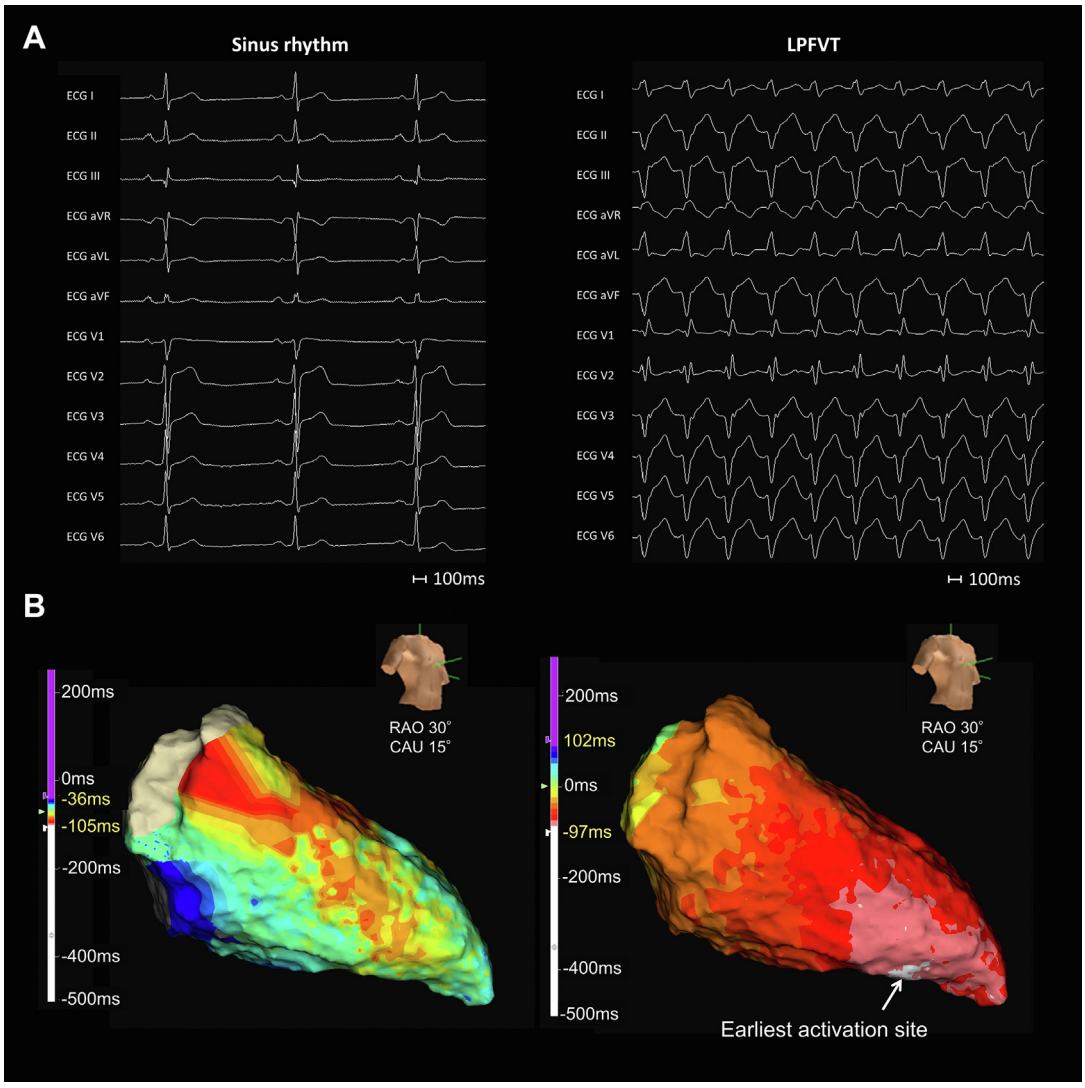

Figure 1 **A:** Twelve-lead electrocardiograms during sinus rhythm (left) and wide QRS complex tachycardia (right). **B:** The activation maps with the absolute dV/dt annotation during sinus rhythm (left) and wide QRS complex tachycardia (right). The activation wavefront on the left ventricular septum propagates from the base to the apex during sinus rhythm and from the apex to the base during the tachycardia. CAU = caudal; LPFVT = left posterior fascicular ventricular tachycardia; RAO = right anterior oblique.

ventricular tachycardia was 54 ms and -49 ms, respectively. Those findings were consistent with LPFVT.

Following the introduction of the Agilis™ NxT steerable sheath (Abbott, St Paul, MN) into the left atrium via a transseptal approach, a 3-dimensional image of the left ventricle was constructed using the HD Grid catheter and EnSite™ X EP System (Abbott, St Paul, MN). The automated annotation of the first deflection on the bipolar electrograms showed that the activation wavefront on the left ventricular septum propagated from the base to the apex during sinus rhythm, while it propagated from the apex to the base during the LPFVT (Figure 1B) (See Supplemental Video 1). High-frequency presystolic potentials (P2) were observed on the left ventricular septum, and the earliest activation site (EAS) of the P2 potentials was almost the same as the EAS of the left ventricular myocardium during the LPFVT. In contrast, the HD Grid catheter recorded minimal P1 potentials in the bipolar electrograms across the splines. However, low-frequency and low-amplitude P1 potentials were observed in the bipolar electrograms along the splines. Interestingly, the omnipolar electrograms, which were created by calculating the signals from 3 adjacent electrodes, exhibited the P1 potentials more clearly than the other bipolar electrograms (Figure 2A). Although the automated annotation algorithm failed to identify the P1 potentials, the manual annotation of the P1 potentials recorded on the HD Grid catheter revealed that they propagated from the base to the apex on the left ventricular septum and toward the EAS of the P2 potentials (Figure 2B) (See Supplemental Video 1).

An irrigated-tip catheter (TactiCath™; Abbott, St. Paul, MN) was inserted into the left ventricle through a transaortic approach. Since the ablation catheter electrograms failed to detect the P1 potentials, we initially applied 30–40 W of

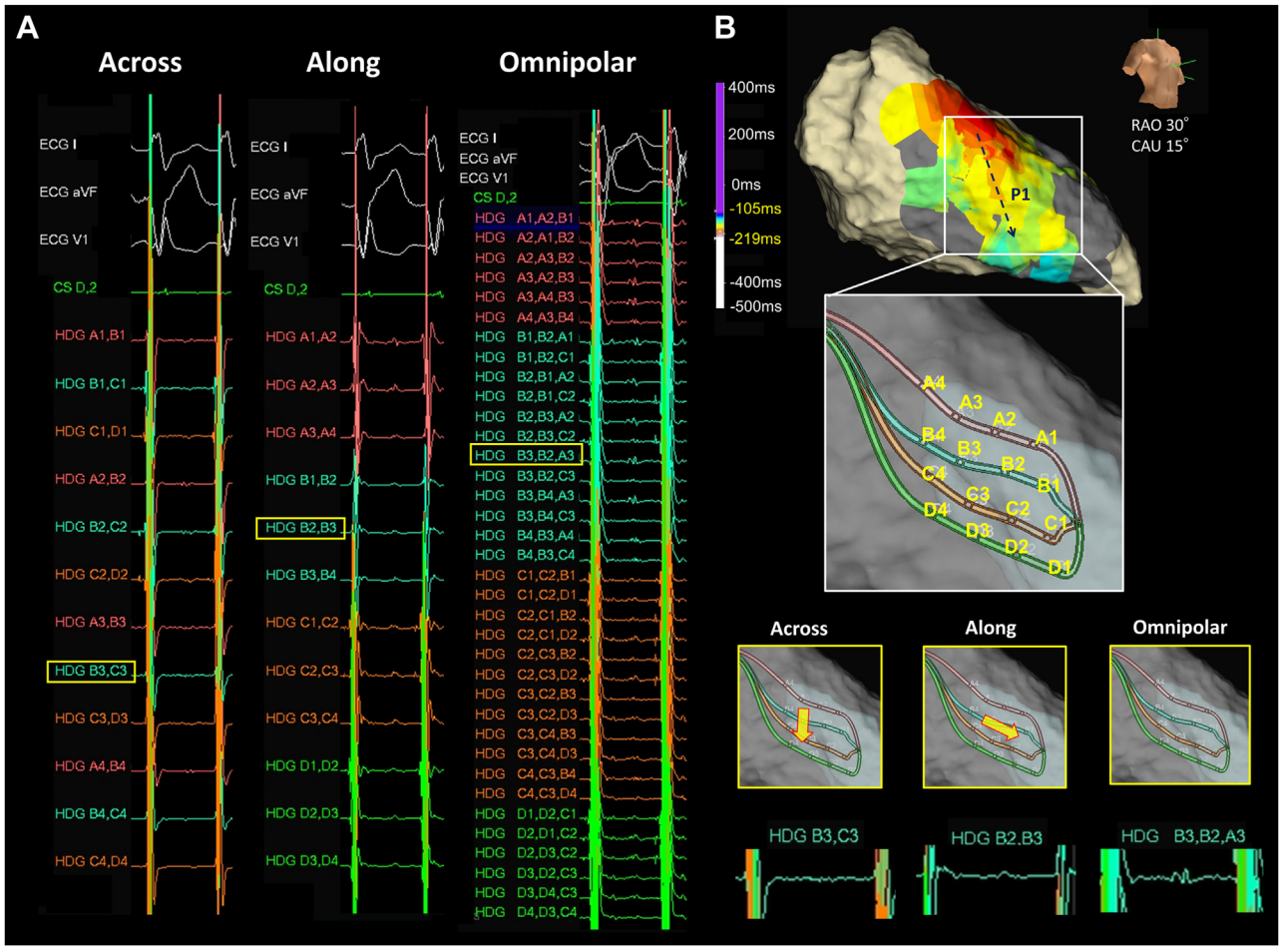

Figure 2 **A:** Representative images illustrating the electrograms obtained with the HD Grid catheter during the left posterior fascicular ventricular tachycardia. The HD Grid catheter was positioned parallel to the left ventricular septum and in contact with the endocardial tissue. The EnSite X system enables the creation of virtual omnipoles using the Omnipolar Technology with the HD Grid catheter. (All cited equipment: Abbott, St Paul, MN.) In this case, the bipolar electrograms showed that P1 potentials were minimally recorded across the splines (eg, HDG B3, C3). Alternatively, low-frequency and low-amplitude P1 potentials were recorded in the bipolar electrograms obtained along the splines (eg, HDG B2, B3). The omnipolar electrograms (eg, HDG B3, B2, A3) created by a group of 3 adjacent electrodes displayed the P1 potentials more clearly than the bipolar ones. **B:** Although the P1 potentials were almost simultaneously recorded during the diastolic phase in the HD Grid electrodes, the manual annotation of the P1 potentials showed the wavefronts propagating from the base to the apex of the left ventricle. The P1 potentials had a wide spatial distribution, and the diastolic pathway was too large to be covered by a single application of the HD Grid catheter. ECG I, aVF, and V_1 represent the surface ECG; CS represents the coronary sinus electrograms; and HDG represents the electrograms of the HD Grid catheter. Other abbreviations as in Figure 1.

radiofrequency energy to the regions exhibiting the earliest P2 potentials. Nevertheless, it proved ineffective in modifying the LPFVT. Then, the radiofrequency energy was gradually applied to the regions upstream of the P1 recorded area. Despite the lack of detectable P1 potentials on the recordings from the irrigated-tip catheter, the application of radiofrequency energy led to a reduction in the tachycardia cycle length and eventually terminated the LPFVT (Figure 3). Because 2 echo beats persisted to be inducible, supplementary radiofrequency energy was linearly applied from the site of the successful ablation to the EAS of the P2 potentials. Finally, no echo beats were induced by programmed stimuli at the end of the session and the P1 potentials were recorded as late potentials during sinus rhythm. The QRS axis and morphology in the inferior leads remained unchanged. Throughout the 10-month follow-up period, the patient exhibited no recurrence of arrhythmia and has remained asymptomatic without the use of antiarrhythmic drugs.

Discussion

Identifying critical Purkinje potentials (P1) is crucial for the successful ablation of an LPFVT.[1–3] The advancement of mapping technologies (eg, high spatial resolution, high sampling rate, and the ability to identify the electrode-tissue contact) and the development of multielectrode catheters with small electrodes and close spacing have greatly enhanced the identification of P1 potentials. Nonetheless, the identification of mid- to late-diastolic P1 potentials is occasionally challenging. Unrecordable P1 potentials can arise from bipoles positioned perpendicular to the endocardial

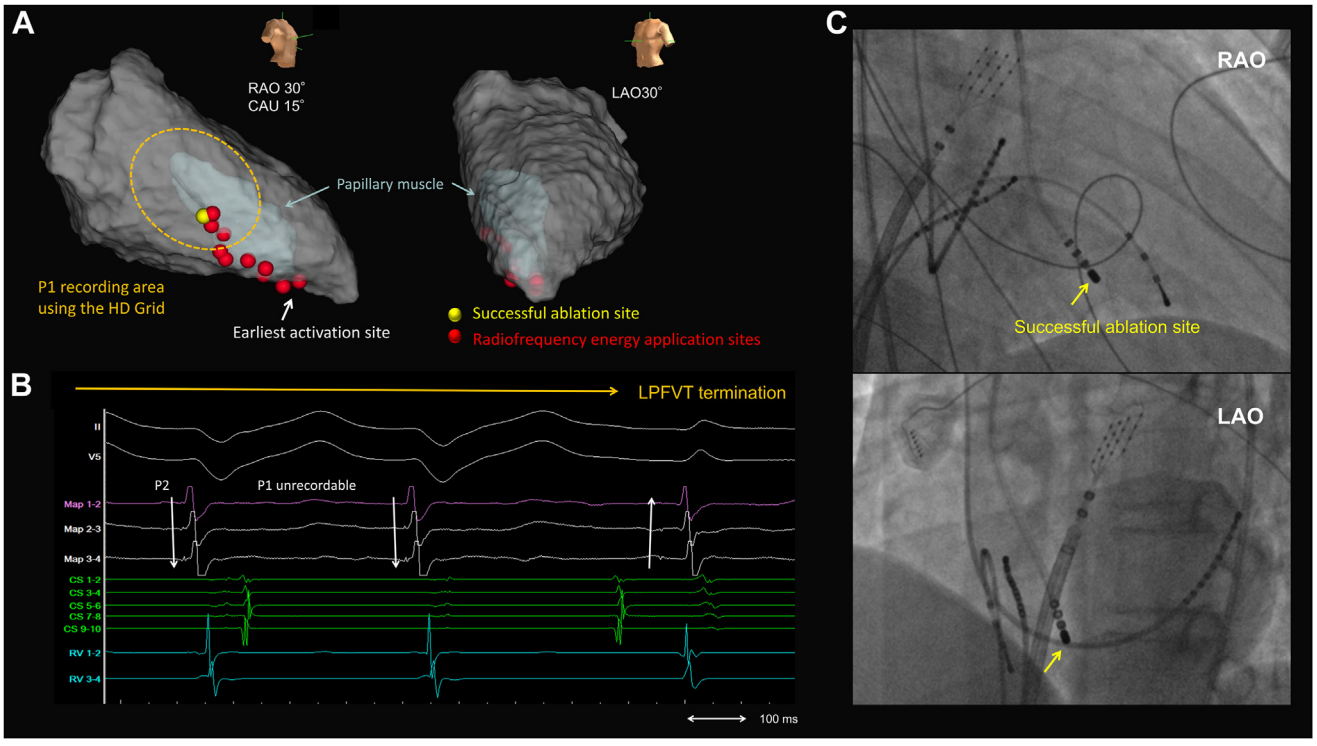

Figure 3 Three-dimensional images (**A**), intracardiac electrograms (**B**), and fluoroscopic images (**C**) of the successful ablation site. **A:** Radiofrequency energy of 35–40 W was applied from the myocardial earliest activation site to the P1 recording area. **B:** Remarkably, the P1 potentials were undetectable by the ablation catheter (Map 1–2), even at the site where the successful ablation was achieved. The surface electrocardiogram is represented by leads II and V_5, whereas the distal electrograms to proximal ones of the ablation catheter are represented by Map 1–2 to 3–4. Similarly, the distal-to-proximal recordings of the coronary sinus are represented by CS 1–2 to 9–10, and the distal-to-proximal electrograms located in the right ventricle are illustrated by RV 1–2 to 3–4. LAO = left anterior oblique; other abbreviations as in Figure 1.

tissue or from the individual variations in the spatial distribution of the P1 potentials.[4–7] However, only a few reports have conclusively linked the directional dependence of bipolar electrograms to unrecordable P1 potentials.

In our case, the HD Grid catheter facilitated a detailed analysis of the P1 potentials. The comparison of the bipolar electrograms along and across the electrode splines exhibited a distinct amplitude of the P1 potentials. Notably, the omnipolar electrograms exhibited greater clarity of the P1 potentials than the other bipolar electrograms. This finding indicated that the recordings of P1 potentials were orientation dependent and the directional dependence may account for the unrecordable P1 potentials. Furthermore, several omnipolar electrograms (eg, HDG D2, D1, C2 in Figure 2A) recorded both P1 and P2 potentials clearly. In contrast, the P2 potentials were not recorded; or if they were, only very small P2 potentials were recorded in the corresponding bipolar electrograms (eg, HDG D1, D2 and HDG C2, D2 in Figure 2A). The greater clarity of both P1 and P2 potentials in the omnipolar electrograms indicates that the OT can describe electrograms independent of the activation axis.[8–10]

According to the previous literature, P1 potentials (the anterograde limb of the tachycardia) are composed of abnormal Purkinje-like fibers on the mid septum, and P2 potentials are normal left posterior fascicular potentials.[1,2] Because the spatial distribution and wavefront direction of the P1 and P2 potentials differ individually,[2,4–7] the angle that maximizes the bipolar electrograms, which is parallel to the activation axis, also differs between the potentials. By incorporating electrogram signals that are concurrently acquired from triangular groups of 3 adjacent electrodes (ie, cliques), the OT enables mathematical transformations and generation of local electrograms unaffected by the catheter orientation. This cutting-edge technology has the potential to record P1 and P2 potentials at the same time even in patients with different P1 and P2 activation axis. Simultaneous recordings of P1 and P2 potentials with omnipolar electrograms may not only help us perform an effective catheter ablation of LPFVT but also allow us to perform a more detailed electrophysiological study, which may help us to address unresolved issues of LPFVTs (eg, the underlying anatomy, electrophysiology, and circuit mechanism).

The directional concept of omnipolar electrograms has been explored when assessing various arrhythmias. The OT eliminates the directional error and maximizes local electrograms by aligning the bipole to the activation axis. Thus, it is especially useful when assessing directional-dependent electrograms including local abnormal ventricular activity.[11] However, important limitations should be recognized while using this technology in the context of the LPFVTs. First,

the contact and parallel orientation of the bipoles with the endocardial tissue is crucial when using the HD Grid catheter. A perpendicular orientation of the bipoles in the absence of sufficient contact with the endocardial surface may create erroneous omnipolar electrograms. Second, even using the latest 3-dimensional mapping system, automated annotation of the P1 potentials remains challenging. Owing to the simultaneous recordings of the low-frequency and low-amplitude P1 potentials along with high-frequency and high-amplitude ventricular myocardial potentials or P2 potentials, the automated annotation technology prioritizes larger potentials than small ones, resulting in the failure of the automated annotation of the P1 potentials. Further investigation is required to determine whether narrowing the window of interest to the diastolic phase and annotation of the first/last deflection can resolve this problem. Lastly, because the ventricular myocardium is activated shortly after the Purkinje activation, mapping with a high sampling frequency of >4 kHz and the use of a ≤ 2 mm interelectrode spacing catheter are advised for efficient detection of the Purkinje activation.[12] The EnSite X system's 360-degree electrogram sampling with integrated novel noise filtering system is pertinent for differentiating the Purkinje potentials from myocardial potentials.

Conclusion

In this case of an LPFVT, the directional dependence of the bipolar recordings was determined to be a cause of unrecordable P1 potentials. While the automated annotation of the P1 potentials was challenging owing to their low-frequency and low-amplitude nature, the use of the HD Grid catheter and OT helped overcome the important limitation of bipolar recordings. Uncovering the critical P1 potentials with OT enabled us to perform successful catheter ablation of the LPFVT.

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Appendix

Supplementary Data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrcr.2023.09.004.

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