Termination of long-duration ventricular fibrillation by catheter ablation

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Introduction

Catheter ablation is effective for refractory ventricular fibrillation (VF) in ischemic cardiomyopathy.[1–6] Focal triggers from the Purkinje system originate at the border zone of the scar, and radiofrequency catheter ablation of those triggers suppresses the recurrence of VF during long-term follow-up.[6] However, it remains unknown if these triggers play a pivotal role in the initiation and perpetuation of VF. We present a case of a patient on hemodynamic support, with refractory long-duration VF, which was terminated by catheter ablation to focal Purkinje activities that became self-terminating after the ablation.

Case report

A 64-year-old man presented with resuscitated VF. He had myocardial infarction 3 years ago and percutaneous coronary intervention was performed for 99% stenosis at the left circumflex artery. The left anterior descending artery showed chronic complete occlusion. During this admission, no ST elevation in the surface electrocardiogram (ECG) was detected. Echocardiography revealed diffuse hypokinesis of the left ventricle (LV) (ejection fraction: 30%). A coronary angiogram exhibited 99% stenosis at the right coronary artery and percutaneous coronary intervention was performed on hospital day 5. Multiple episodes of VF recurred the next day; thus, venoarterial extracorporeal membrane oxygenation (ECMO) was introduced. Repeat coronary angiogram did not exhibit restenosis or thrombus. Intravenous amiodarone (1250 mg/day) and ultra-short-acting beta-blockers (landiolol hydrochloride, 20 μG/Kg/min) were also started. On day 17, a VF storm occurred, and multiple direct current (DC) shocks proved ineffective in obtaining a sinus rhythm. Surface ECG exhibited ventricular fibrillatory rhythm; however, some ECG leads transiently exhibited partially organized morphology (Supplemental Figure 1B).

On hospital day 21 (after 16 days of ECMO support), catheter ablation was performed for refractory long-duration VF. VF continued for 5 days despite 90 attempts of direct current shocks. The LV endocardial mapping during VF revealed an extensive low-voltage area on the LV septum and inferior wall (Figure 1A and Supplemental Figure 2). At a relatively higher voltage area at the middle LV septum (arrow in Figure 1A), almost regular Purkinje activities could be identified preceding each local endocardial ventricular activation (Figure 1B). The mean cycle length (CL) of Purkinje activity was 330 ms. At the significantly low-voltage area of the LV apical septum (site no. 1 in Figure 1A), small Purkinje activities were recorded during VF (Figure 2A). Small electrograms of the LV muscle were irregular and some

KEY TEACHING POINTS

- During long-duration ventricular fibrillation (VF) in a human, almost regular Purkinje activation followed by ventricular activation was observed on the left ventricular septum.
- Radiofrequency catheter ablation to the sites with Purkinje activation reduced the frequency of Purkinje activities and created a conduction block between Purkinje fibers and the working myocardium. After the elimination of Purkinje activities, long-duration VF terminated spontaneously.
- The Purkinje network plays a pivotal role in both the initiation and the perpetuation of VF.

KEYWORDS Catheter ablation; Extracorporeal membrane oxygenation; Purkinje activities; Radiofrequency; Ventricular fibrillation
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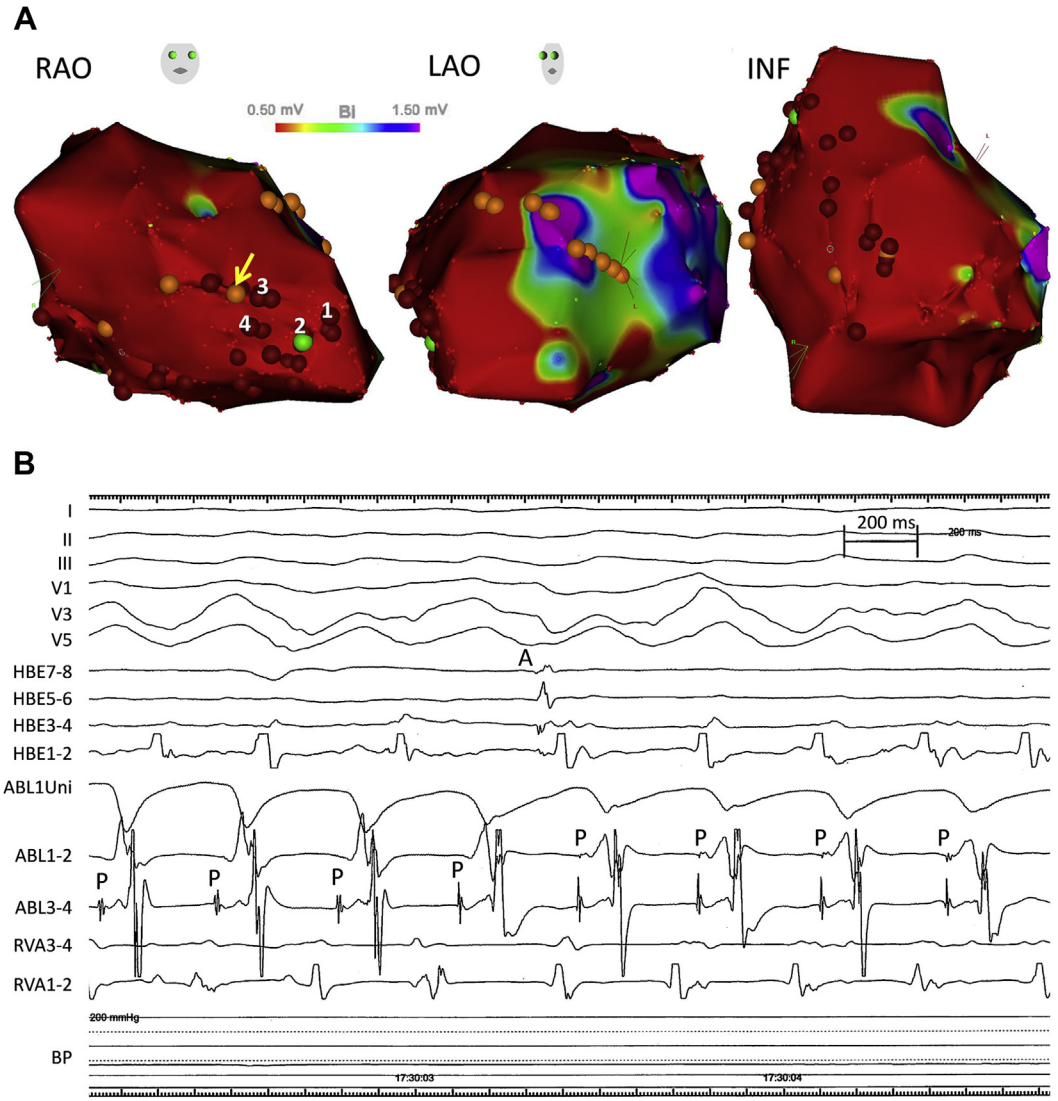

Figure 1 Electroanatomical voltage map during long-duration ventricular fibrillation (**A**), and intracardiac recording at the left ventricular (LV) septum (**B**). At a relatively higher voltage area at the middle LV septum (*arrow* in **A**), almost regular Purkinje activities could be identified preceding each local endocardial ventricular activation (**B**).

of them followed Purkinje activity (mean CL: 420 ms). Ventricular electrograms on the right ventricular (RV) septum were irregular in morphology and CL. After the application of radiofrequency energy at this site, the frequency of Purkinje activities was significantly reduced. At the adjacent site (site no. 2 in Figure 1A), Purkinje activities were recorded again (mean CL: 460 ms) (Figure 2B) and radiofrequency energy was delivered. After delivery of the radiofrequency energy at this site, Purkinje activities were completely dissociated from ventricular signals and the mean CL of Purkinje activities was prolonged to 650 ms (Figure 2C). Both RV and LV septal signals became organized in morphology and CL (mean CL: 330 ms). After delivery of the radiofrequency energy at the adjacent sites, the mean CL of Purkinje activities was prolonged (710 ms) (Figure 2D). Finally, after 4 applications of radiofrequency energy at the apical LV septal area (sites no. 1–4 in Figure 1A), Purkinje activity was completely eliminated (Figure 2E). VF terminated spontaneously approximately a minute after the ablation (Figure 3). There was no Purkinje potential at this site during sinus rhythm. After the restoration of the sinus rhythm, an LV voltage map was created (Supplemental Figure 2). Other trigger beats from the Purkinje system initiated the VF; however, it terminated spontaneously within 5 seconds (Supplemental Figure 3). Additional radiofrequency applications for other trigger beats were performed (total radiofrequency energy deliveries: 32 applications, 28 minutes).

After the ablation, the patient remained in sinus rhythm with several episodes of self-terminating VF. Unfortunately, his hemodynamics did not improve even during the sinus rhythm, and he suffered severe brain damage. The patient died a few days after the ablation.

Discussion

Our case findings suggest that the Purkinje network plays a pivotal role in both the initiation and perpetuation of VF.

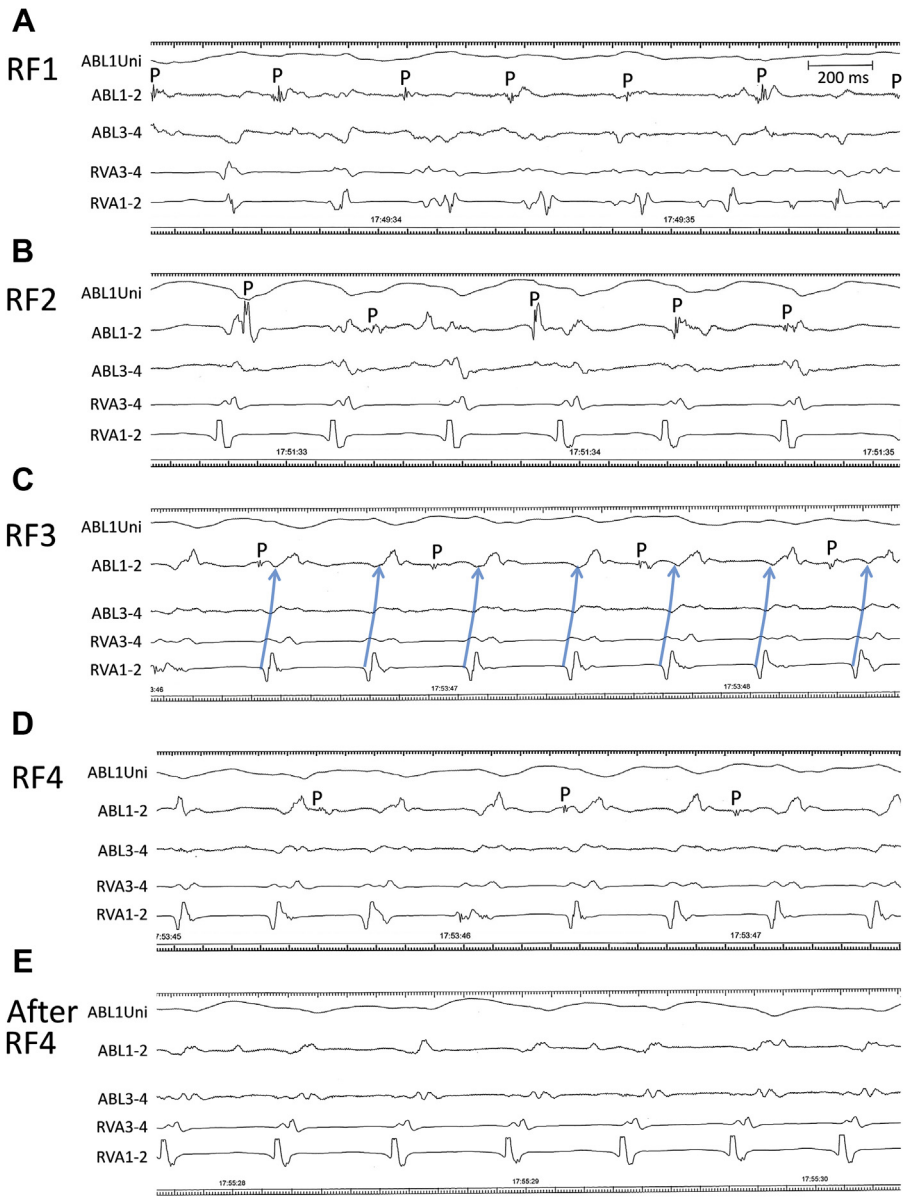

Figure 2 Intracardiac electrograms at ablation sites. After 2 radiofrequency (RF) energy applications at the apical left ventricular septal area, local ventricular signals were organized (*arrows* in **C**) and Purkinje activity was dissociated from ventricular signals. After 4 RF energy applications Purkinje activity at this area was completely eliminated (**E**).

To our knowledge, this is the first case report that explores mapping and ablation undertaken during long-duration VF in a human.

Purkinje cells are relatively resistant to ischemia, as they are supplied by cavital blood, and the amount of glycogen in them is much higher than that in myocardial cells.[7] In the Purkinje cells that survive ischemia, abnormal automaticity owing to the elevated resting membrane potential and triggered activity as the result of early/delayed afterdepolarizations with distinct proarrhythmic Ca^{2+}-mediated mechanisms can occur.[8–10] Surviving Purkinje fibers crossing the border zone of the myocardial infarction demonstrate heightened automaticity, triggered activity, and supernormal excitability, which, when coupled with prolongation of the action potential duration in this region, may result in the necessary milieu for polymorphic ventricular tachycardia / VF. The role of Purkinje fibers in maintaining VF is less documented than its role in VF initiation. Nevertheless, several experimental studies have evaluated Purkinje activity during VF on isolated animal hearts using multielectrode arrays. Panitchob and colleagues[11] demonstrated that 3 distinct patterns of LV endocardial activation existed in dogs during long-duration VF that persisted over 1–2 minutes, ie, distinct organization patterns of chaotic, regular, and synchronized activity. The chaotic pattern was predominant in early VF, but the regular pattern emerged as VF progressed. The synchronized pattern only emerged occasionally during late VF. They demonstrated that activity on the endocardium (and Purkinje system) may drive these activation patterns in long-duration

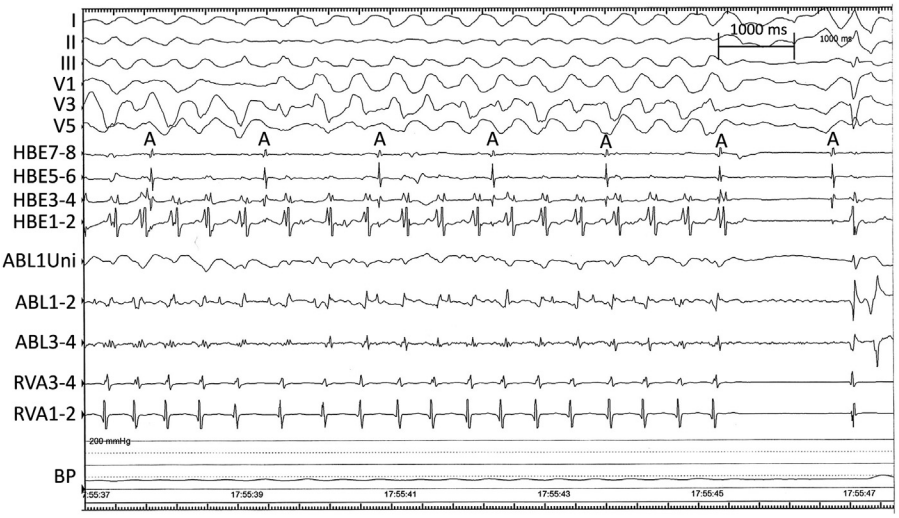

Figure 3 Spontaneous termination of ventricular fibrillation after the ablation.

VF. The regular and synchronized patterns of activation were driven by rapid activations on the endocardial surface that blocked and broke up transmurally, leading to an endocardial-to-epicardial activation rate gradient as long-duration VF progressed. In our case, although we did not perform LV multisite simultaneous mapping or epicardial mapping, the VF pattern seemed to be synchronous. As Purkinje activities on the LV septum during VF were almost regular, the CL of activities was longer than the activity on the surface ECG (mean CL: 310 ms), and there was sometimes a pause in ventricular activities.

Jackson and colleagues[12] investigated the electrophysiological mechanisms of long-duration VF in Langendorff-perfused human hearts. They demonstrated that long-duration VF in the human heart is characterized by focal endocardial activity with mid-myocardial wave break, and isochronal maps of the LV endocardium identified Purkinje potentials as preceding and predominating endocardial activations. Their findings suggest that during the development of long-duration VF in humans, a progressive change occurs from a rhythm driven by reentry to the rhythm driven by focal activations from the Purkinje fibers on the endocardium.

Purkinje activation has been shown to precede myocardial activation; therefore, suppression of VF by ablation of the Purkinje activation might be possible. Dosdall and colleagues[13] demonstrated that the chemical ablation of the Purkinje system by Lugol solution led to earlier spontaneous termination of long-duration VF in dogs. Pak and colleagues[14] also reported VF suppression by the ablation of the Purkinje network near the papillary muscles in dogs and rabbits. However, VF could not be suppressed by the same endocardial ablation in pigs. These discrepancies are due to the different distribution patterns of the Purkinje network of animals. Pigs and other hoofed animals have a different distribution of the Purkinje system compared to dogs, rabbits, and humans. Purkinje fibers in dogs and humans are in the subendocardial layer and do not course transmurally, as they do in pigs.[15]

The anatomical distribution of Purkinje fibers in humans is similar to that in dogs. Thus, if Purkinje fibers play a role in maintaining long-duration VF, the activation patterns seen during long-duration VF in dogs should be a better representation of long-duration VF in humans. Dosdall and colleagues[13] demonstrated that Purkinje fibers and myocardial activations were recorded on the ventricular endocardium in isolated and perfused dog hearts during long-duration VF. After the chemical ablation of the Purkinje system in the RV and LV endocardium by the application of Lugol solution, only myocardial activations were identified during induced VF and VF terminated spontaneously. These findings are similar to our case; however, endocardial necrosis by Lugol solution is not specific to Purkinje fibers. Pak and colleagues[14] performed endocardial mapping during VF in ischemic dog hearts and found the highest dominant frequency was near the posterior papillary muscle with Purkinje activations. Radiofrequency ablation to the posterior papillary muscle and the adjacent area reduced the VF inducibility from 100% at baseline to 22% after ablation.

Microreentry, abnormal automaticity, and triggered activity in Purkinje fibers are possible mechanisms for the initiation of VF.[8–10] In addition, the previous experimental studies[11–14] and the present case report revealed that Purkinje fibers play a role in maintaining long-duration VF. In the present case, we first ablated the almost regular Purkinje activities at the scar border during VF. After the restoration of sinus rhythm, ablation targets were other trigger beats from the Purkinje system. Elimination of Purkinje potential at the small specific area seems to be needed; however, the determination of the specific area needs further investigation.

Conclusions

Refractory long-duration VF, in a patient on ECMO, terminated spontaneously after catheter ablation of Purkinje

activations. This finding suggests that the Purkinje network plays a pivotal role in both the initiation and perpetuation of VF.

Appendix

Supplementary data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrcr.2020.10.002.

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