Role of Purkinje Fibers in the Maintenance of Ventricular Fibrillation

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Many experimental and clinical studies on the mechanisms of ventricular fibrillation (VF) have been performed over the past 10 decades. The underlying mechanisms of VF have been discussed from different points of view: initiation and maintenance. It is beyond question that reentry, triggered activity or automaticity initiates VF, but the mechanism of its maintenance is not fully determined. Although the duration from the onset of VF may affect its electrophysiological features, maintenance of VF has been explained by the coexistence of 2 or more unstable multiple wavelets or mother rotors.1

In recent studies, however, attention has been directed to the role of Purkinje fibers in the initiation and maintenance of VF.2–6 The Purkinje fiber system, which plays a critical role in harmonious myocardial contraction and relaxation via its efficient propagation properties and unique geometrical distribution,7 is naturally worthy of note when discussing a possible source of VF. Because of the conspicuous heterogeneity in the action potential duration of Purkinje fibers compared with the working myocardium, it is likely that this system offers a substrate for reentry to sustain VF.

The VF threshold (VFT), expressed by the amount of electrical stimulation to induce VF, has been used to quantify the susceptibility of the heart to VF.8–10 Horowitz et al reported a significant difference between endocardial and epicardial VFTs in the left ventricle.8 They considered that the coexistence of ordinary myocardium with shorter repolarization characteristics and Purkinje fibers with a long refractory period in the endocardium facilitated the induction of VF. Later, Damiano et al attempted to clarify the role of the Purkinje network on ventricular vulnerability.9 In their study, the baseline VFT was 26±2 mA and increased to 53±56 mA after total ablation of the endocardial surface by applying Lugol’s solution. This observation was in agreement with Horowitz’s suggestion. In a more recent study using a 3-dimensional model of the ventricles,2 the Purkinje system was shown to give rise to initial reentry, which led to the establishment of intramyocardial reentry independent of the Purkinje network.

Purkinje fibers are known to be so resistant to ischemia that they survive and continue to function even during long-lasting VF,11 which may explain why VF terminates spontaneously in hearts with subendocardial chemical ablation, and suggests that Purkinje fibers play a significant role in the maintenance of VF.5

Recently, Tabereaux et al investigated the activation pattern during VF.3 They found that Purkinje fibers are highly active even 10 min after the onset of VF. In addition to retrograde propagation from the working ventricular myocardium to the Purkinje fibers, they noticed antegrade propagation also occurred from the Purkinje fibers to the working ventricular myocardium. This phenomenon supports the hypothesis that Purkinje fibers play an important role in the maintenance of VF, as well as in its initiation.

In a current study by Wu et al using isolated rabbit hearts via optical mapping of endocardial and epicardial activations, the close relationship between the maintenance of VF and repetitive endocardial focal discharges has been clearly demonstrated. Re-initiation of VF after unsuccessful electrical defibrillation was apparently caused by endocardial focal discharges. The methods used in their study are rather sophisticated and the results observed are plausible.

In addition, that study is similar to a previous study of defibrillation. In 1981, Ouyang et al reported the defibrillation threshold (DFT) in open-chest dogs with reversible 10-min coronary occlusions.13 DFT in Watt seconds of electrically induced VF was 9±7. The DFT of spontaneous VF after coronary occlusion was 14±10, and 18±21 s in spontaneous VF after reperfusion. Thus, twice as much energy was required for defibrillation of VF caused by occlusion or reperfusion but without electrical stimulation. They considered that electrically induced VF and spontaneous VF do not share totally identical metabolic or pathologic derangements. Their observation suggests that a certain triggering factor is working during spontaneous VF to hamper electrical defibrillation. In those days, because detailed analysis of activation in the ventricles was not available, the difference between electrically induced VF and ischemia-related spontaneous VF was unknown. Based on the observations in the study by Wu et al,12 repetitive endocardial focal discharges during VF offer an attractive reason for the observations by Ouyang et al.

Because many clinical studies have shown that electrical activity originating from the pulmonary veins causes atrial fibrillation, isolation of these veins has become a rational and efficient strategy to cure atrial fibrillation. While repetitive firing in the pulmonary veins activates the atria, activa-
tion from the atria retrogradely invades the pulmonary veins. Thus, interaction between the pulmonary veins and the atria is considered to be, if not solely, a mechanism of persistent AF.

In a study by Janse et al., ectopic beats appeared from myocardial tissue in rabbit hearts, even when the subendocardium had been destroyed; that is, in the absence of the Purkinje network. Interestingly, these ectopic beats failed to degenerate into VF. However, the absence of Purkinje fibers did not fully eliminate prolongation of VF in canine hearts. The discrepancy in the results among experimental studies may partly be attributable to differences in the size of the heart or to differences in species-related electrophysiological properties of the myocardial tissue. In a recent study by Pak et al., destruction of Purkinje fibers by ablation of the posterior papillary muscle and left ventricular posteroseptum attenuated VF inducibility in both dogs and pigs.

When the size of the human heart is taken into consideration, it seems unlikely that extensive ablation of the Purkinje fibers would dramatically reduce the inducibility of VF or facilitate spontaneous termination of VF. Nevertheless, in patients who are suffering from an electrical storm resistant to conventional treatments, ablation targeting the Purkinje network may be a last resort. Considering the extensive distribution of the Purkinje fibers, further studies are needed to identify the critical region of the system specifically crucial for maintaining VF.

References