Differential Electrograms Computed from Unipolar Endocardial Recordings Improve Purkinje Activation Identification

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Abstract

Recent studies have indicated that the Purkinje system plays a critical role in the onset and maintenance of certain arrhythmias. Unipolar electrograms were recorded at 8 KHz from the endocardium during sinus rhythm and ventricular fibrillation. Using the unipolar recordings, bipolar, quadipolar, and octapolar, and Laplacian electrograms were created. Purkinje potentials were more readily identified with bipolar and octipolar electrograms than with unipolar recordings. The first temporal derivatives of the electrograms aided in distinguishing Purkinje potentials. Differential electrograms and their temporal derivatives facilitate Purkinje potential identification by reducing common noise in the electrograms and far field effects recorded by the unipolar signal. Combined analysis of the unipolar electrograms, differential computed electrograms, and their derivatives improve identification of Purkinje activation from endocardial electrical recordings.

1. Introduction

Under normal conditions, the Purkinje system aids in the spread of electrical impulses throughout the ventricles. However, recent studies have implicated the Purkinje system as the site of arrhythmia initiation, and ablation of the Purkinje system has eliminated arrhythmia initiation.[1, 2] The Purkinje system may be an important source of focal activation during long duration ventricular fibrillation (VF),[3, 4] and chemical ablation of the Purkinje system changes the activation rate and duration of VF.[5] The Purkinje system may also play a significant role in near threshold defibrillation shock failure.[6, 7]

Since the Purkinje system is limited primarily to the endocardial surface in canines as well as humans,[8, 9] direct recording of Purkinje activation is most effectively performed on the endocardial surface of the heart. High sampling rates are needed to accurately capture the sharp, narrow, signals observed when a Purkinje fiber activation occurs near an extracellular electrode.[10] Even with electrodes on the endocardial surface and high sampling rates, Purkinje activations may be difficult to distinguish from myocardial activations. The bulk myocardial signal may be relatively large due to far field effects and the large mass of the myocardium compared to the thin Purkinje layer on the endocardium. The purpose of this study is to investigate various differential electrograms to improve the ability to distinguish Purkinje and myocardial activations in extracellular recording techniques.

2. Methods

A canine heart was isolated, perfused through the left main coronary artery, and the left ventricular endocardium was exposed through an incision through the right ventricle and septum, as described elsewhere.[4, 5] A 4x12 electrode plaque with electrodes at 1 mm intervals (Figure 1) was placed over the base of the anterior papillary muscle. Unipolar electrograms were bandpass filtered between 0.5 Hz and 4 KHz and sampled at 8 KHz. Recordings were made during intrinsic rhythm

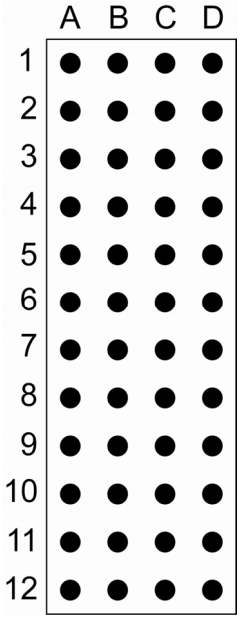

Figure 1 The top left electrode on the plaque is the unipolar recording, $U_{A,1}$.

and during unperfused long duration VF.

Bipolar, Quadripolar, Octopolar, and Laplacian electrograms were computed by subtracting unipolar electrograms as specified in Equations 1-4.

$$Bipolar1=U_{A2} - U_{A1} \quad \text{(Eq. 1)}$$

$$Quadripolar1=2*U_{A2} - U_{A1} - U_{A3} \quad \text{(Eq. 2)}$$

$$Octipolar1=4*U_{B2} - U_{B1} - U_{B3} - U_{A2} - U_{C2} \quad \text{(Eq. 3)}$$

$$Laplacian1=R*(20*U_{B2} - 4*(U_{B1} - U_{B3} - U_{A2} - U_{C2}) - U_{A1} - U_{C1} - U_{A3} - U_{C3}) \quad \text{(Eq. 4)}$$

Where $R=1/(6*\sigma*d^2)$ and σ=tissue resistance and d=distance between electrodes.

Purkinje activations were manually identified as short duration (<2 ms), rapid deflections using criteria that we have used previously,[4, 5] which has been adapted from criteria used by others to identify Purkinje activations.[11-15]

3. Results

From the 48 (12x4) unipolar electrograms, 44 (11x4) bipolar, 40 (10x4) quadripolar, 20 (10x2) octipolar, and 20 (10x2) Laplacian electrograms were created. Electrograms from a representative sinus beat are shown in Fig. 2.

Purkinje activations were rarely identified in the unipolar recordings (Fig. 2A). The first temporal derivatives of the unipolar signals aided in identifying Purkinje activations, however, the derivatives had significant 60 Hz noise that made Purkinje identification difficult.

Purkinje activations were more easily identifiable in the bipolar electrograms and their first temporal derivatives. During VF, electrogram amplitude and polarity were highly dependent upon the orientation of the waveform as it propagated past the electrodes. A positive deflection indicated that the wavefront passed in the direction of row 1 to row 12 (of Fig. 1). A wavefront that passed from row 12 to row 1 caused a negative deflection in the bipolar electrogram. Wavefronts that passed perpendicular to the rows (from column A to D or D to A) causes minimal deflections on the bipolar recordings.

Quadripolar electrograms increased the relative size of the Purkinje activations in comparisons to the myocardial activations. Quadripolar electrograms were not sensitive to the directionality of the waveforms in the row 1-12 or 12-1 direction, but as with the bipolar electrograms, quadripolar electrograms were smaller in amplitude when the wavefronts passed primarily from columns A-D or D-A.

Octipolar electrograms exhibited obvious and clear Purkinje activations, particularly in their first temporal derivatives. While the electrograms were similar in morphology to the unipolar electrograms, the Purkinje activations were accentuated because rapid activation of the Purkinje fibers is accentuated by the subtraction of the unipolar electrograms surrounding the central unipolar electrograms. The common 60 Hz noise and far field signals were also subtracted by the creating the octopolar recording. Octopolar electrograms were also less sensitive to wavefront directionality.

Laplacian electrograms were similar in morphology to the octopolar electrograms. These electrograms are the least sensitive of the differential electrograms to wavefront directionality. Purkinje potentials were very clear with the Laplacian electrograms. However, these electrograms are affected significantly by bad unipolar electrograms.

4. Discussion and conclusions

We have previously published guidelines for improved Purkinje detection from plunge needle experiments.[16] Among the findings from the previous publication are: 1) use a minimum sampling rate of 4 KHz., 2) record near the endocardium, and 3) use bipolar rather than unipolar recording electrodes. In the current study, we have limited our recordings to the endocardial surface and have recorded at 8 KHz. The main goal of this study was to determine whether differential electrograms computed from unipolar electrograms facilitated the identification of Purkinje activations.

After recording endocardial electrograms with a multielectrode plaque, differential electrograms may be computed to improve identification of Purkinje activations. Bipolar electrograms provide a substantial improvement in Purkinje identification and a reduction in common noise between channels over unipolar electrograms. Bipolar electrograms also provide information as to the directionality of wavefront conduction. Octipolar electrograms provide high Purkinje to myocardial activation signal ratios and are not sensitive to wavefront direction of propagation. Quadripolar and Laplacian electrograms did not facilitate Purkinje activation identification substantially over bipolar or octipolar electrograms, respectively. However, the quadripolar and Laplacian electrograms were more susceptible to errors from a single bad unipolar electrogram. Therefore, we recommend bipolar and octipolar electrogram analysis to identify Purkinje activations from endocardial plaque electrodes.

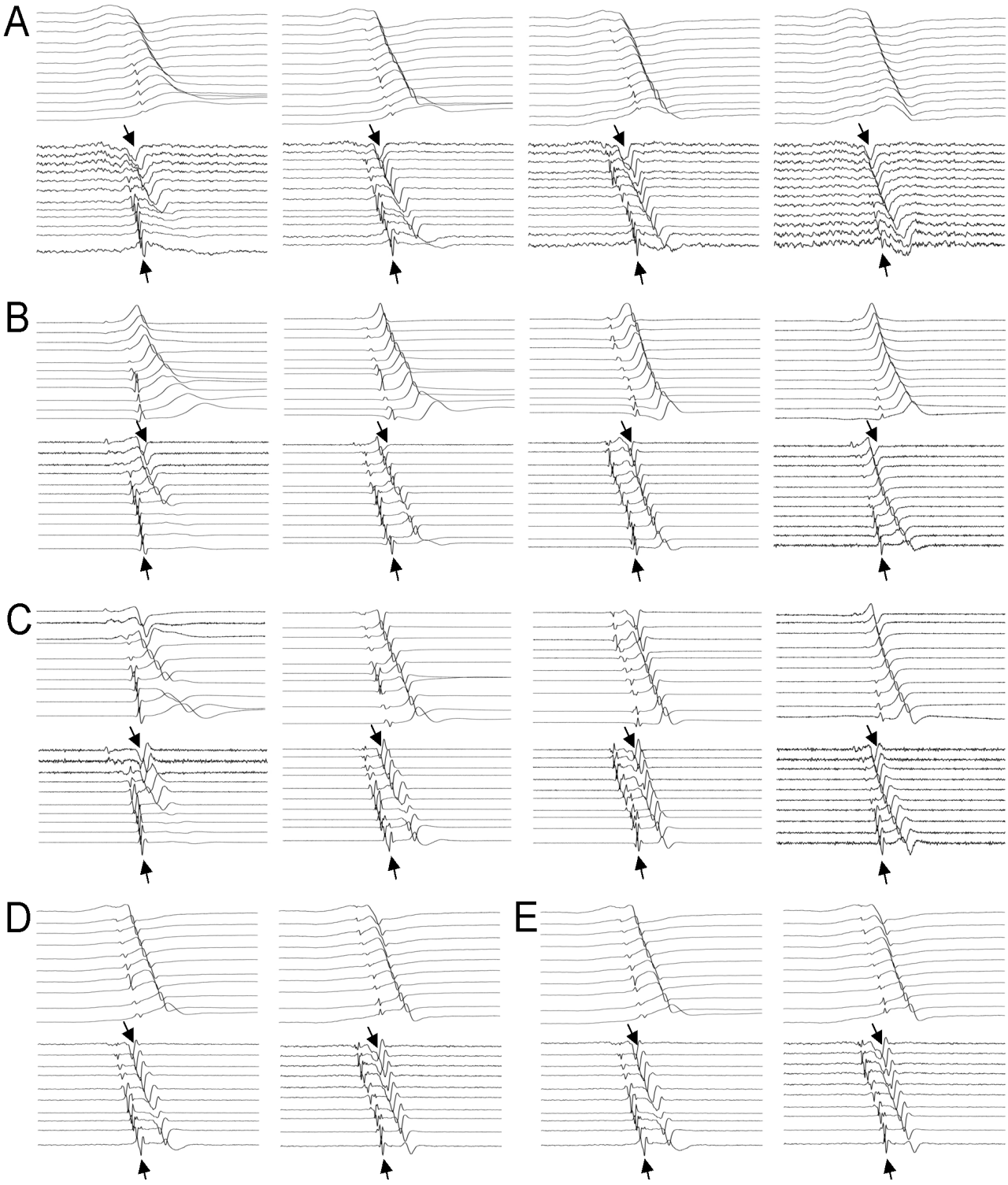

Figure 2 Electrograms (top set of traces in each panel) and their first temporal derivatives (lower set of traces in each panel). Unipolar (panel A), bipolar (panel B), quadripolar (panel C), octipolar (panel D), and Laplacian (panel E) electrograms are shown for a single sinus beat. The 4 columns and 12 rows from Fig. 1 are shown in Panel A. Purkinje activations (upward arrows) and myocardial activations (downward arrows) are marked on the first temporal derivatives.

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