Mobility of Epicardial Rotors During Human Ventricular Fibrillation

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Introduction

The mechanisms that sustain ventricular fibrillation (VF) remain controversial.

Experimental studies of VF in animal hearts have shown that VF can be sustained by multiple re-entrant sources [1] or a single persistent re-entrant source [2], whilst other studies have shown a low incidence of epicardial re-entry [3]. Stability of re-entry may depend on the dynamics of rotor cores.

The aim of this study was to investigate the mobility of epicardial rotors during VF in the human heart. We used phase singularity analysis with electrical maps of the entire ventricular epicardial surface.

Methods

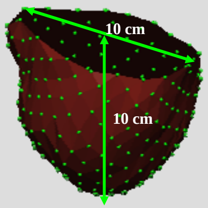
Data acquisition: In 10 patients undergoing cardiac surgery, VF was induced by burst pacing, and a 20-40 s episode of fibrillatory activity was sampled at 1 kHz over the entire ventricular epicardium using a sock containing 256 unipolar contact electrodes connected to a UnEmap system [4,5].

The epicardial electrode sock during surgery

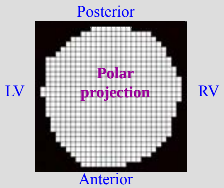
Selection of electrograms: A proportion of the signals had poor signal-to-noise ratios. Frequency analysis (fast Fourier transform) was used to reject signals with dominant components < 1.5 Hz or > 45 Hz.

Geometry: (Fig. 1a) The 3D locations of the electrodes were projected onto a circular 2D polar plot (Fig. 1b). Signals were linearly interpolated from the electrodes onto a fine regular grid (100x100 pixels) and mapped onto the 3D epicardial geometry (Fig. 1c)

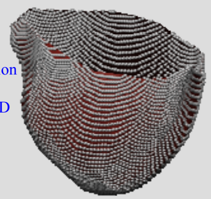
(1a) 3D representation of the epicardial geometry with electrode locations indicated in green.



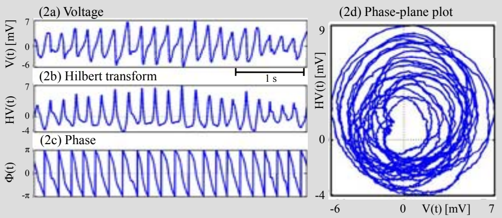
(1b) Polar projection of the epicardium superimposed with a 2D regular grid.



(1c) 3D representation of the grid points obtained from the 2D projection.

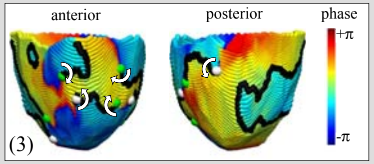


Activation times were computed at the minimum negative slope of voltage [6]. A signal de-trending algorithm [7] was applied to set the voltages at the activation times to zero.



Phase was computed from the phase-plane plot (Fig. 2d), determined using the Hilbert transform [8] for each de-trended signal. Phase maps were represented on the 3D epicardial surface (Fig. 3).

Phase singularities (PS) are the tips of re-entrant waves on the epicardial surface (epicardial rotors). PS were identified (Fig. 3) using a method based on the topological charge [9]. Rotor trajectories were tracked using an algorithm that allowed PS to move up to 15 mm between time-frames, whilst connecting PS that disappeared for < 100 ms (approximately half a cycle).

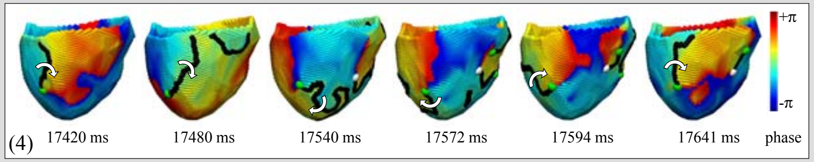


(3)

Activation wavefronts (WF) correspond to spatial isochrones of activation time. Due to signal de-trending, WF can equivalently be determined from the isolines of zero phase under the Hilbert transform. WF were identified using an active edge method [7] and traced on the 3D epicardial surface (Fig. 3).

Results

Epicardial re-entry: Many persistent epicardial rotors were observed during VF (e.g. Fig. 4). One or more persistent rotors could be detected for more than 75% of the total VF recording time.



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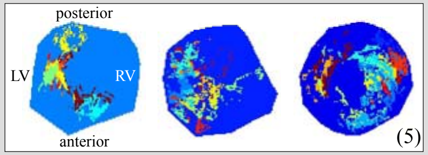


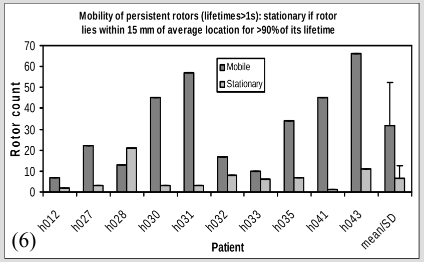
(5)

Rotor meander: The trajectory of each persistent epicardial rotor core was tracked over its lifetime. A variety of rotor meander patterns were observed within and between patients. Three examples are shown in Fig. 5 using the polar projection of the mapped epicardial surface. Each colour indicates the region spanned by one rotor. Meander patterns showed no anatomical preference nor orientation.

Rotor mobility: The temporal mean core location was determined over the lifetime of each persistent rotor. A rotor was classified as stationary if its core remained within 15 mm of its mean location for more than 90% of its lifetime (otherwise the rotor was classified as mobile).

Using the above criteria, the numbers of mobile and stationary rotors varied from patient-to-patient (Fig. 6). In 9/10 patients, there were more mobile than stationary persistent rotors.

Over all patients, the mean ± SD number of mobile rotors (32 ± 21) was greater than the number of stationary rotors (7 ± 6, P<0.01).



(6)

Summary

Human VF is characterised by a small number of persistent mobile epicardial rotors.

This finding has implications for understanding the mechanisms that sustain VF in the human heart, and thus for treatment of this condition.

Acknowledgments

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