Novel Capacitive Electrode for Cardiac Model

Christopher R. Gloschat*, Hui Fang†, John A. Rogers†, Igor R. Efimov*

†Department of Biomedical Engineering, The George Washington University
‡Department of Materials Science and Engineering, University of Illinois Urbana-Champaign

Introduction

Multi-parametric high-resolution mapping of the heart is fundamental to furthering our understanding of the pathophysiology of various disease states. Recent developments in flexible/stretchable electronics have created a set of tools and fabrication processes capable of creating conformal cardiac devices able to withstand chronic deployment. Additionally, they are capable of versatile scaling allowing them to map the entire heart surface as well as to provide sub-millimeter resolution. In order to function as a chronic implant, the limitations of standard metal oxide electrodes, primarily degradation and limited scalability, must be overcome. Here we present a novel capacitive electrode capable of measuring relevant cardiac electrical activity while overcoming the limitations of metal oxide electrodes.

Methods - Electrode Design

- Exploded-view schematic illustration (left) and a photograph (right) of a completed capacitively-coupled flexible sensing system with 396 nodes in a slightly bend state. The arrows in the left illustration highlight the key functional layers. Inset on the right shows a magnified view of a few nodes. (b) Circuit diagram for a node in this capacitively coupled array, with annotations for each component (left), and an optical microscope image of the cell (middle). A schematic of the circuit cross sections (right) illustrates the mechanism for capacitively coupled sensing through an SOI layer in an underlying transistor.

Methods - Electrophysiology Study Cont.

- Representative electrical and optical signals captured simultaneously on a Langendorff perfused rabbit heart at multiple cycle lengths (300, 250, and 200 ms). (b) Interpolated spatial activation maps derived from these data. Top row shows activation as measured during absence of VF. Bottom row vs. time is ventricular pacing. The dashed box specifies the window of time corresponding to two ventricular cycles of VF. The marks 0, 60, 120, and 180 indicate the initial phase values of the respective signals at the beginning of the reentrant cycle. (c) Voltage, phase and phase singularity maps at six time points corresponding to the dark lines specified in (b). Number 1, 2, and 3 on the maps mark the locations where the signals in (a) were taken. Voltage and phase data indicate a reentrant cycle of VF. A phase singularity commonly refers to a point on a phase map around which all values of phase (i.e., –π to +π) are represented. The phase singularities are identified as the ±1 values associated with regions of the phase map where this occurs. Optical signals from the sensing electronics area also match well with electrical recordings (data not shown).

Results - Study of Ventricular Fibrillation

- These representative electronic node signals taken from a heart during VF. The dashed box specifies the window of time corresponding to two ventricular cycles of VF. The 0, 60, 120, and 180 indicate the initial phase values of the respective signals at the beginning of the reentrant cycle. (a) Voltage, phase and phase singularity maps at six time points corresponding to the dark lines specified in (b). Number 1, 2, and 3 on the maps mark the locations where the signals in (a) were taken. Voltage and phase data indicate a reentrant cycle of VF. A phase singularity commonly refers to a point on a phase map around which all values of phase (i.e., –π to +π) are represented. The phase singularities are identified as the ±1 values associated with regions of the phase map where this occurs. Optical signals from the sensing electronics area also match well with electrical recordings (data not shown).

Conclusion

Our data serves as a proof-of-concept that capacitive electrodes are capable of measuring relevant cardiac electrical activity. Comparison of capacitive electrode recordings to simultaneously recorded optical mapping measurements facilitated the establishment of morphological criteria for both activation and repolarization in capacitive signals. Future work will include the integration of the electrode into a conformal whole ventricular epicardial device and the quantification of VF characteristics.

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