Proceedings of the 2022 Design of Medical Devices Conference
DMD2022
April 11-14, 2022, Minneapolis, MN, USA

DMD2022-1069

DEVELOPMENT OF AN EPICARDIAL MAPPING TANK FOR NONINVASIVE ELECTRICAL MAPPING OF EX VIVO LARGE MAMMALIAN HEARTS

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ABSTRACT

Electroanatomical mapping provides key insights into cardiac function and arrhythmia location. Epicardial mapping allows for the recording of electrograms from the body surface that can be combined with an anatomical geometry to create a real-time functional voltage map of cardiac electrical activity. Isolated heart models, like those studied on the Visible Heart® apparatus, provide a valuable platform for medical device design but are often limited to modified 3-lead electrocardiograms that do not provide anatomically specific electrical data. To provide detailed electroanatomical data for experiments on the Visible Heart® apparatus, a novel modified epicardial mapping tank was created that utilizes the CardioInsight™ software to create a map of reanimated hearts. The epicardial mapping tank is composed of 252 electrodes that are distributed across acrylic plates that surround the isolated heart. Half normal saline provides continuity to the electrodes, allowing uninterrupted signal acquisition. The system is fully removable and can be positioned while maintaining reanimation. To date, 5 swine hearts and 1 human heart have been reanimated and mapped in the epicardial mapping tank. The unique datasets generated from the epicardial mapping chamber will be a critical tool in pacing, ablation, and defibrillation experiments as well as provide valuable information relative to conduction system physiology.

Keywords: Electroanatomical mapping, isolated heart models, electrophysiological recording system

1. INTRODUCTION

Noninvasive electroanatomical mapping is an area of increasing clinical interest for the treatment of cardiac arrhythmias. Yet, the use of endocardial mapping catheters can in themselves cause arrhythmias and thus are not well tolerated in hemodynamically unstable patients. This is particularly true when mapping in the ventricles, which are very prone to irritation. The CardioInsight™ system (Medtronic) is an epicardial mapping system that creates electroanatomical maps from body surfaces [1]. The patient wears this three-piece vest during a CT scans which establishes the patient's anatomy relative to the vest electrodes. The patient geometry is then combined with signals acquired at the bedside or in the electrophysiology (EP) lab. From this data, single-beat voltage maps and phase electroanatomical maps are made to guide cardiac ablation procedures.

FIGURE 1: A depiction of the CardioInsight™ vest on a human torso.

The Visible Heart® apparatus is a custom reanimation system that allows for direct visualization of functional large mammalian hearts. We commonly utilize a clear modified Krebs-Henseleit buffer as a perfusate which typically sustains the given large mammalian heart for 5-7 hours and also enables direct visualization with endoscopic cameras. Swine hearts are reanimated on a routine basis; on rare occasions, human hearts have also been reanimated on the Visible Heart® apparatus. Human hearts deemed not viable for transplantation have been donated to the Visible Heart® Laboratories for research from the local procurement agency (LifeSource, Minneapolis, MN, USA). Human hearts tested on this platform facilitate unique opportunities to study functional anatomies and perform research to test medical device prototypes and experimental protocols, serving as an intermediary step between benchtop setups and clinical trials.

To further the types of translational experiments we can perform on the Visible Heart® apparatus, a custom epicardial mapping tank was designed for use on the reanimated large mammalian hearts. Since the clinically available vests are single-use and cost-prohibitive, a reusable system was designed to map hearts reanimated using Visible Heart® methodologies [2]. Pilot studies to test the feasibility of using the CardioInsight™ system to measure electrograms from an isolated swine heart were performed with electrodes from a deconstructed vest [3].

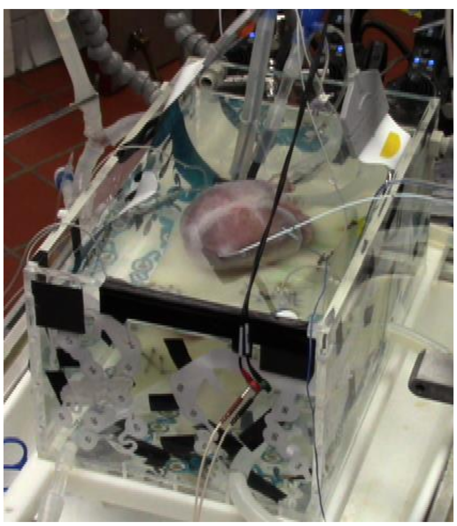

FIGURE 2: A reanimated swine heart in the early generation epicardial mapping tank [3].

The success of the early experiments provided the motivation for a more permanent solution. The development of this epicardial mapping chamber will enable the collection of critical cardiac electrophysiological information of large mammalian hearts (including human) gained by looking at the electrograms at specific locations that correlate with the underlying anatomy.

2. MATERIALS AND METHODS

Preliminary experiments were performed to ensure sufficient cardiac function in the submerged heart. An extracardiac buffer comprised of 0.45% sodium chloride conducts signals from the myocardium to the surrounding electrodes.

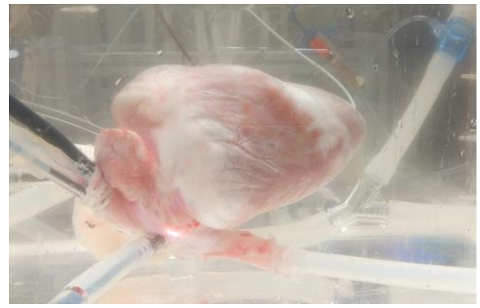

FIGURE 3: A reanimated swine heart submerged in half normal saline.

Several design iterations were considered to maximize the capabilities and flexibility of the mapping tank to accommodate a wide range of anatomies. To replicate the vest electrodes, holes for 252 Ag/AgCl 8-millimeter electrodes were laser cut into acrylic. Electrodes were arranged to cover all sides of the heart in 4 removable pieces so to allow for easy placement or removal during a given study. The electrode plate mapping the anterior surface of the heart rests on notches on the surrounding tank and contains 16 holes to allow for epicardial access and to reduce surface tension.

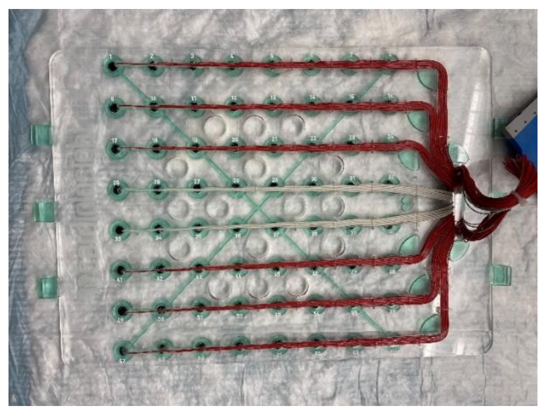

FIGURE 4: Top plate of electrodes from the epicardial mapping tank. Holes in the acrylic allow direct access to the anterior surface of the heart.

In order to maintain perfusion of the heart while inserting the mapping tank, the bottom fixture that situates on the posterior of the heart is composed of 4 smaller acrylic slats connected using flexible hinges. To place the bottom plate, the right sided pulmonary veins are easily disconnected, and the plate is carefully slid underneath the still-beating heart until it sits within four acrylic posts on the bottom of the tank to standardize positioning across hearts.

FIGURE 5: The bottom electrode plate composed of thin acrylic sheets connected by flexible hinges.

Electrodes were arranged to be in the approximate locations as they are on the CardioInsight™ patient vest. Each electrode was wired to the pinout connection corresponding to the desired electrode number. Continuity testing was performed to ensure proper wiring of each electrode to the corresponding electrode number in the CardioInsight™ software.

FIGURE 6: The completed epicardial mapping tank with all 252 electrodes, shown with a 3D printed heart.

3. RESULTS AND DISCUSSION

To date, the system has been used on both reanimated swine hearts (n=5) and uniquely on a reanimated human heart (n=1). Each heart was reanimated using Visible Heart® methodologies and kept viable for 5-8 hours [2]. The hearts were initially perfused in the tank without the electrode plates to allow for utilizing fluoroscopy to allow for unobstructed visualization of the heart and cardiac devices.

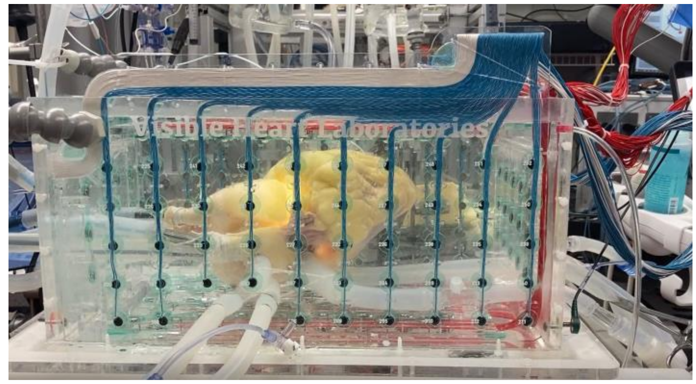

FIGURE 7: Side profile of a reanimated human heart in the epicardial mapping tank on the Visible Heart® apparatus.

The colors of the electrodes seen on the projected vest computer representation indicate the relative status and quality of a given signal: green for good, red for poor, and yellow to indicate that the trace is being displayed on the right side of the screen. In this preliminary study (Figure 8), over 75% of the electrodes recorded viable signals here.

FIGURE 8: Unipolar electrocardiograms recorded from a reanimated human heart in the CardioInsight™ tank on the Visible Heart®.

Following signal acquisition on functional hearts using the epicardial mapping tank, hearts were and will be CT scanned within the tank to correlate with electrode positioning. We consider that a standard CT scan will be used as the default geometry for swine hearts since these hearts do not have significant differences in anatomical variabilities. Each reanimated human heart, which can range in weight from 300 to 1000 grams, each with distinct anatomy, will have a unique CT scan for improved accuracy in each segmentation process, as shown in Figure 9 below.

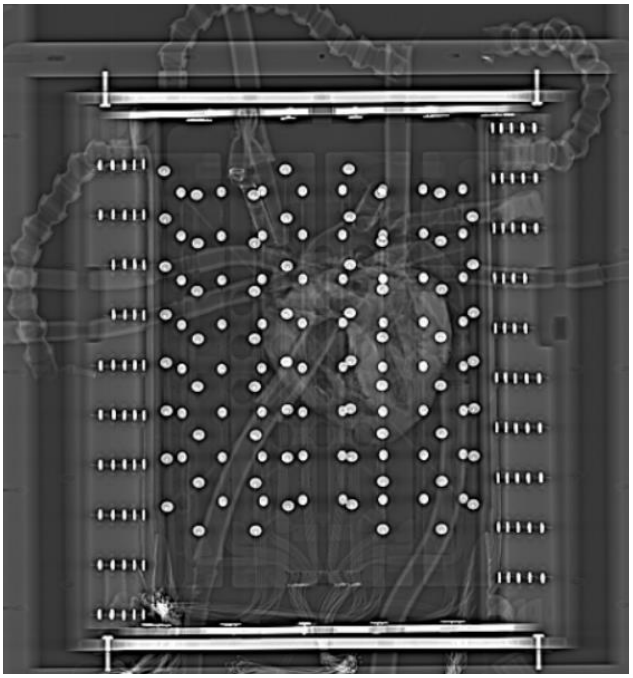

FIGURE 9: A CT scan of a previously reanimated human heart positioned in the epicardial mapping tank with all 252 electrodes.

In the CardioInsight™ segmentation software, masks are created from the CT scan to outline cardiac chamber boundaries. Electrodes are then identified and labeled appropriately to allow for proper pairing of the signals acquired to the positioning relative to underlying anatomy. Once the segmentation is complete, phase maps and single beat maps can be created, as shown in Figure 10.

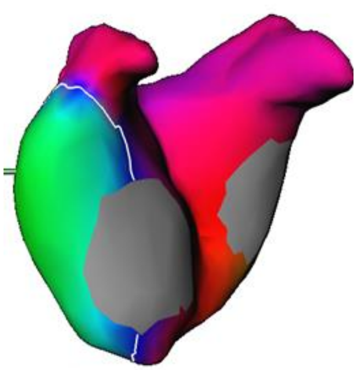

FIGURE 10: An example of the single-beat voltage maps that can be generated using the CardioInsight™ system.

In these experiments, we demonstrated that we can successfully transfer hearts without disrupting perfusion. Normal sinus rhythm and cardiac output were validated using external ECG and ventricular pressures. There was minimal electrical noise affecting during these recordings but could be modified by repositioning of endoscopic cameras.

4. CONCLUSION

The unique datasets generated during these epicardial mapping experiments will provide valuable information about large mammalian heart conduction system physiology (including human) and the therapeutic effects of pacing, ablation, defibrillation and others. This electrical mapping data along with hemodynamic and anatomic data will also serve as high quality critical inputs needed for computational modeling. Use of the CardioInsight™ system within the Visible Heart® apparatus can also be used to aid in future iterations of the CardioInsight™ system design.

ACKNOWLEDGEMENTS

We would like to acknowledge LifeSource and the donors for the human hearts used in this study. We would also like to thank Mark Borash, the other graduate students within the VHL, and Dr. Tinen Iles for feedback on early prototype designs.

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