Design of a Novel Perfusion System to Perform MR Imaging of an Isolated Beating Heart

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Isolated mammalian hearts have been used to study cardiac physiology, pharmacology, and biomedical devices in order to separate myocardial characteristics from the milieu of the intact animal and to allow for increased control over experimental conditions. Considering these benefits and that MRI is the "gold" standard for measuring myocardial function, it was considered desirable to have a system which would allow simultaneous MR imaging of an isolated beating heart. Here we describe a unique portable system, which enables physiologic perfusion of an isolated heart during simultaneous MR imaging. A two unit system was designed to physiologically support a large mammalian isolated heart during MR imaging were a modified Krebs-Henseleit perfusate was used as a blood substitute. The first unit, which resides in an adjacent support room next to the scanner, contains all electronically powered equipment and components (with ferromagnetic materials) which cannot operate safely near the magnet, including (1) a thermal module and custom tube in tube heat exchanger warming the perfusate to 38°C; (2) a carbogen tank (95% O_2 5% CO_2) and hollow fiber oxygenator; and (3) two centrifugal blood pumps which circulates and pressurizes the left and right atrial filling chambers. The second unit, which resides next to the magnet and is free of ferromagnetic materials, receives warmed, oxygenated perfusate from the first unit via PVC tubing. The isolated hearts were connected to the second unit via four cannulae sutured to the great vessels. A support system placed inside the scanner on the patient bed secured the hearts and cannulae in the correct anatomical position. To date, this system was tested in a 1.5 T Siemens scanner using swine hearts (n=2). The hearts were arrested with St. Thomas cardioplegia and removed via a medial sternotomy. After cannulation of the great vessels, reperfusion, and defibrillation, four-chamber and tagged short-axis cine loops were acquired using standard ECG gating. Tagged short-axis images obtained at the base, mid-ventricle, and apex were used to measure the following functional parameters for one heart: LV end-diastolic volume=38.84 ml, LV end-systolic volume=23.23 ml, LV stroke volume=15.6 ml, LV ejection fraction=40.18%, and peak LV circumferential strain=16%. The feasibility of MR imaging an isolated, four-chamber working large mammalian heart was demonstrated using a custom designed and built portable MRI compatible perfusion system. This system will be useful in studying in vitro cardiac function (including human hearts) and developing MRI safe biomedical devices and MRI guided therapies in a controlled setting.

A Soft-Polymer Piezoelectric Bimorph Cantilever-Actuated Peristaltic Micropump

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For this work, a peristaltic micropump was fabricated. Actuation of the micropump was accomplished with piezoelectric cantilevers. To date, a minimal number of soft polymer-based micropump designs, have explored the use of piezoelectric materials as actuators. The fluidic channel for the micropump was fabricated using PDMS and soft lithography. A novel and very simple template fabrication process was employed, where the use of a mask and clean room facilities was not required. Replica molding to the template produces both, a channel measuring $\sim$95 μm in height, and a rounded cross-sectional geometry, the latter of which is known to be favorable for complete valve shutoff. Clamps were adhered to the tips of the cantilevers, and used to secure in place aluminum valves. The valves had finely machined tips [3 mm $\times$200 μm(L$\times$W)] on one surface. These tips served as contact points for the valve making contact with the PDMS membrane surface, and were used for the purpose of opening and closing the channels. The cantilevers were secured in place with in-house manufactured micropositioners, which were used to position the valves directly over the PDMS channel. The micropump was thoroughly tested where the variables characterized were maximum attainable backpressure, flow rate, valve open/close characteristics, and valve leakage. The effect of the phase difference (60°, 90°, and 120°) between the square wave signals delivered to each of the three cantilevers was investigated for flow rate and maximum attainable backpressure. Of the three signal phases, the 120° signal demonstrated the largest flow rate range of 52–575 nL/min (0.1–25 Hz), as well as the highest attainable backpressure value of 36,800 Pa (5.34 psi). The valve shutoff characteristics for this micropump was also examined. Fluorescein was trapped inside the microchannel, where the fluorescent signal was monitored throughout the valves open/close cycle with the aid of an epifluorescent microscope. It was found that the fluorescent signal went to zero with the valve fully closed, supporting the conclusion that the valve completely closes off the channel. Further evidence of this claim was demonstrated by observing the valve leakage characteristics. An electronic pressure sensor was used to collect data for this experiment, where it was found the valve was able to hold off 36,800 Pa (5.34 psi), only loosing 2% of this pressure over 10 minutes. In conclusion, it has been shown this micropump outperforms many existing micropump designs, and is suitable for integration into a variety of both macro, and microdevice platforms. Experiments are currently underway to examine how the flow and valving characteristics change for valves with different tip dimensions. A discussion will also be given for improved fabrication techniques, where injection molding is currently being used as the fabrication method to examine the performance changes associated with different cross-sectional PDMS channel geometries. The end goal for use of this micropump is twofold; 1) integration into a micro-free flow separation device, and 2) integration into a capillary electrophoresis instrument for use in direct-sampling neuroscience experiments.

