Silicon Based Ultrasonic Microprobes for Cardiac Signal Recording

CNF Project # 1122-03
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Abstract:
Three dimensional mapping of physioelectrical activities in in vitro cardiac tissues is highly desirable for the study of the mechanism and development of cardiac arrhythmias. Important information can be obtained for prediction and prevention of arrhythmias, especially ventricular arrhythmia—one of the leading causes of mortality in the United States. In this project, we design and manufacture ultrasonically actuated silicon microprobes for multi-site potential recording from inside the heart, while the ultrasonic actuation reduces insertion force and minimizes tissue damage. Probe tips with multiple recording sites have been successfully inserted into canine heart tissue and cardiac signals were recorded under different conditions. The penetration force—maximum force encountered by the microprobe during insertion into the tissue—on different biological tissues were studied and its dependence on ultrasonic driving and probe dimension was analyzed. These results illustrate not only the encouraging prospect of 3D electrical recording for cardiac arrhythmia studies, but also the novel application of vibrational energy at the micro-scale.

Fabrication:
The device consisted of a silicon ultrasonic horn actuator [1] with a longitudinal λ/2 resonance at 75 kHz. Two thin beam tips were defined at the small end of the horn to be driven longitudinally. The thickness of the tips (ranging from 70 µm to 140 µm) was defined by DRIE on the front side and the probe was released by wet etching from the backside. The tip length varied from 5 mm to 1 cm for penetration of a heart wall of different thickness. A dummy probe without tip was bonded to the probe for symmetry and to reduce bending mode of the tips. PZT4 plates were bonded to the device for ultrasonic driving. The device is clamped to a customized PC board at resonance node. The PC board also provides metal pads for electrical connection from the Pt/Cr electrodes on the probe through wire bonding. A ground layer was also patterned on top of the conduction paths to reduce cross-talking between channels.

Results:
Cardiac signal recording was conducted on an isolated and perfused canine heart. Recordings were obtained from isolated perfused canine heart during pacing, following the induction of ventricular tachycardia, and during the transition from ventricular tachycardia to ventricular fibrillation. Local conduction velocity of 0.60±0.03 m/s was observed from the multichannel recordings from the canine right ventricular wall under epicardial pacing. Signals from different recording sites were compared and phase/morphology difference can be used for later reconstruction of physioelectrical wave propagation in the heart. Furthermore, signals recorded with/without the presence of ultrasound showed little difference other than some easily filtered high frequency noise, indicating the low voltage ultrasonic driving posed no significant modification on heart cells’ electrical activities.

Penetration and cutting force measurements show that both forces reduced as ultrasonic driving voltage increased. The penetration force—the maximum force encountered by the probe during penetration—is found to reduce with increasing ultrasonic driving voltage, on both excised canine right ventricular muscle and chicken breast muscle. The rate of force decrease varies with tissue type and microprobe dimension. Laser Doppler interferometer measurements showed that flexural vibration modes are excited in the silicon microprobe by longitudinal ultrasonic actuation and may contribute to the force reduction. With ultrasonic actuation, the silicon microprobes are inserted into an isolated perfused canine heart without breakage or significant buckling, under 10 Vpp actuating voltage.

References:
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Figure 1, top left: Multi-channel recording with silicon microprobes integrated with ultrasonic horn actuator.

Figure 2, bottom left: Flexural vibration mode excited in silicon microprobe by longitudinal ultrasonic actuation.

Figure 3, above: Penetration force on canine cardiac tissue and chicken breast tissue decreases with increasing ultrasonic driving.