Benchtop experiments of an ultrasound fiber optic temperature measurement system for atrial fibrillation ablation procedures

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Abstract. In this paper, we developed and tested an ultrasound fiber optic temperature measurement system for atrial fibrillation (Afib) ablation procedures. Currently, Afib ablation procedures lack an efficient way to provide a clinical end. To address this, we put forward a unique non-contact approach to measure the temperature on the ablated tissue. The temperature on the tissue is detected by measuring the acoustic velocity of the ultrasound signal, which is generated and detected by optical fibers. Benchtop experiments were performed on a bovine liver to validate the developed temperature measurement system. Experimental results indicated that the system had successfully registered the temperature changes on the surface of the bovine liver. The temperature measurement system can be further used to control the ablation dosage.

1. Introduction

Afib is the most common chronic cardiac arrhythmia, a leading cause of stroke, and a significant contributor to heart failure and death [1-2]. Cardioversion, antiarrhythmic or rate control drugs, surgery, and catheter ablation are current treatment options for Afib patients [3]. However, drugs and cardioversion have limited positive effects on patients while invasive surgery has both, lengthy recovery time and greater potential for infection [4]. Another method namely Ablation, can cure Afib in early stages. But, currently the ablation dosage is estimated blindly by the ablation duration and surface temperature. Therefore, there is a risk of overheating the ablation area and damaging normal tissue; or the dosage of the ablation area can be insufficient, which results in high procedure repeatability. Repeat procedures are reportedly occurring 30% or more, which limits the efficacy and safety of this therapy, while adding significant costs [5].

The developed fiber optic method can provide a unique non-contact approach to measure the temperature on the ablated tissue and then, the ablation dosage can be controlled based on the temperature of the ablated area [6]. The temperature on the tissue is detected by measuring the acoustic velocity of the ultrasound signal, which is optically generated and detected by optical fibers. This method has two advantages: compact size (Optical Fiber is ~250 μm in diameter) and the immunity to the electromagnetic interference (EMI). The compact size of the optical fiber makes it very easy to be
integrated into any endoscope system and the immunity to EMI makes the technology to be used in an operation room without any interference to other equipment [7-9].

Also, in this paper, we report the bench top experiments that were performed on bovine liver to validate the capability of temperature measurement system.

2. Methodology

Ultrasound can be generated using the material that absorbs laser energy and undergoes thermal expansion, which is called the photoacoustic principle. The fiber optic ultrasound transducer was fabricated using coating gold nanocomposite, of photoacoustic material, on the tip of a 600 µm multi-mode optical fiber (FT600UMT, Thorlabs). A typical acoustic pulse generated by the generator is shown in figure 1.

![Figure 1. A typical pulse generated by the generator.](image)

The fiber optical ultrasound receiver was made based on Fabry–Pérot interference. A PMDS layer was coated on the tip of a single-mode fiber (SMF-28, Corning). When an incident light is illuminated on the tip of the fiber, the light reflects on two interfaces. The two reflected lights will interfere with each other and generate a FP interference pattern. The deformation of the parylene is sensitive to the pressure change. Thus, the reflected interference pattern is shifted due to the pressure change caused by the acoustic signal. By interrogating the interference pattern shift, the acoustic signal can be detected.

The transducer and the receiver were bonded together by tapes to keep them in tight contact and parallel to each other. The tips of two fibers were on the same horizontal plane. Before conducting benchtop experiments on a bovine liver, the fibers’ ability of detecting temperature in water was verified first. The setup for the preliminary experiment was shown in figure 2. The probe, consisting of the transducer and the receiver, was put in a water container and perpendicular to a glass slide on the container bottom. A thermometer (Traceable Waterproof Thermometer, Fisher Scientific) was used to measure the temperature as a reference. The water container was put on a heating platform (PC-162, Corning).

![Figure 2. The setup for the preliminary experiment in water.](image)
The water was heated from room temperature to 50 ºC, and then cooled to room temperature. Signals were recorded at 25, 30, 35, 40, 45, 50 ºC in both heating and cooling period. The cycle was repeated three times to evaluate the sensor’s repeatability. The calibration results were illustrated in figure 3.

![Figure 3. The calibration result of the fiber optic probe.](image)

The standard deviations of the increasing and decreasing cycles were small. The biggest error value of two data in the same temperature was 0.12 µs. The time range in the whole experiment was 1.27 µs. The hysteresis was 9.4 %. The hysteresis was low and the sensor’s repeatability was good. Thus, the fiber optic probe showed the capability of measuring the temperature of water in the ultrasound propagation path.

3. Experiments and results

After the preliminary experiments, benchtop experiments on a bovine liver were then conducted and its setup was shown in figure 4. An ablation probe (RF 3000, Boston Scientific) was used as the heating source. It was buried within the liver and generated heat to heat up the liver. The same thermometer was also used as a reference. The pair of fiber optic ultrasound transducer and receiver were used to detect the temperature on the surface of the liver. As the temperature of on the surface of the liver changed, the ultrasound signal was shifted in the time domain.

![Figure 4. The setup for the bovine test.](image)
4. Conclusion

This paper presents a fiber optic temperature measurement system consisting of a transducer made with the gold nanocomposite, a photoacoustic material, and a receiver based on Fabry–Pérot interference. Its capability of detecting temperature both in water and on a bovine liver was validated by measuring the time-of-flight along the propagation path. The system’s repeatability and linearity were proven to be good during the experiment. We believe this system provides a good method for doctors to measure real-time temperature on the ablation area during Afib to control the ablation dosage. In the near future, we plan to perform in vivo testing to validate the system’s application.

5. References

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