Influence of Temperature Probe Sheathing Materials During Ultrasonic Heating

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Abstract—The influence of sheathing materials upon temperature probes used during the monitoring of ultrasonic heating was measured. The measurements show that the sheathing can be heated in a manner not representative of the temperature rise occurring in the surrounding material, altering the probe readings.

Introduction

In the course of investigating ultrasonic hyperthermia, it became apparent that the sheathing around the temperature probes used to monitor changes in temperature might influence the temperature readings, due to such effects as differential ultrasonic heating of the

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protective sheath and changes in the thermal conductivity in the immediate surround of the probes. This prompted us to design a nonexhaustive experiment to compare the ultrasonic absorption of the sheathing material with that of the phantom material or tissue it displaces. We were particularly interested in Teflon sheathing material because of its widespread use and its biocompatible properties. For further comparison, we also tested additional materials under the same conditions. The experiment measured the temperature rise of both sheathed and unsheathed thermocouples while subjecting these probes to ultrasonic heating within a large water reservoir. The results of this test showed that the sheathing material has a significant influence on the readings of the probes, and the type of materials determines the magnitude of that influence.

Procedure

We filled a tank with water, the tank being of the appropriate size and shape to hold enough water to submerge our temperature probes, to provide a reasonable heat sink to remove heat conducted from the irradiated sheaths and probes without significantly affecting the ambient temperature of the water, and to avoid unwanted multiple reflection artifacts. The probes, copper/constantan thermocouple probes 0.25 mm in diameter, were connected to an Analog Devices AD2036 digital thermometer designed to interface with these thermocouples. An analog output was connected to a strip chart recorder to record the temperature rise of the probes during heating. The ultrasonic transducer was a special heating transducer made by Panametrics (part number MD3240, serial number 127701).

To perform the heating experiment, we submerged the probes in the water and allowed the probe to come to thermal equilibrium with the water. This temperature became the reference temperature from which to calculate the temperature rise of the probe. We then excited the transducer with 100 W of forward electrical power at a frequency of 1.014 MHz and directed the ultrasonic beam toward the thermocouple by properly positioning the heating transducer in the water. The diameter of the beam at the probe's position was approximately 5.2 cm. By watching the digital thermometer, we could determine the transducer position that gave the maximum temperature rise at the probe. We then held that position until the probe (and its protective sheathing) came to thermal equilibrium. By subtracting the reference temperature from this heated temperature, we were able to determine the maximum temperature rise of the probe during ultrasonic heating. The strip chart recorder provided a hard copy of this temperature rise. To assure no deviations in temperature rise due to linearity or sensitivity differences between probes, the same thermocouple was used for all heating trials.

The following is a list of materials used during the heating experiment.

1) Unsheathed thermocouple for reference measurement.

2) Solid Teflon cylinder with an outer diameter of 3.5 mm and a 0.51 mm central hole for snug placement of the thermocouple.

3) Ultrasonic phantom material cylinder with an outer diameter of 5.0 mm and the thermocouple probe being centrally placed inside this cylinder. The phantom had the ultrasonic properties of muscle, with ingredients of water, graphite, agar, and n-propanol and constructed as described by Berlew *et al.* [1].

4) Polyethelene catheter with an inner diameter of 1.12 mm and an outer diameter of 1.65 mm.

5) Teflon catheter with an inner diameter of 1.12 mm and an outer diameter of 1.65 mm.

6) Fused silica capillary tubing with an inner diameter of 0.53 mm and an outer diameter of 0.69 mm.

7) 22 AWG thin wall Teflon tubing with an inner diameter of 0.71 mm and an outer diameter of 1.24 mm.

Results

The rise in temperature recorded for each of the trials is tabulated in Table I and plotted for comparison in a bar graph in Figs. 1 and 2.

TABLE I
Results of Heating Trials

Material	Initial Temperature	Equilibrium Temperature	Temperature Rise
(1) Unsheathed Thermocouple	21.8 °C	23.0 °C	1.2 °C
(2) Teflon Plug	21.0	88.9	67.9
(3) Phantom Plug	20.8	35.0	14.2
(4) Polyethelene Catheter	21.3	23.3	2.0
(5) Teflon Catheter	21.6	34.2	12.6
(6) Fused Silica Tubing	22.0	23.0	1.0
(7) Teflon Tubing Thin Wall	21.9	39.0	17.1

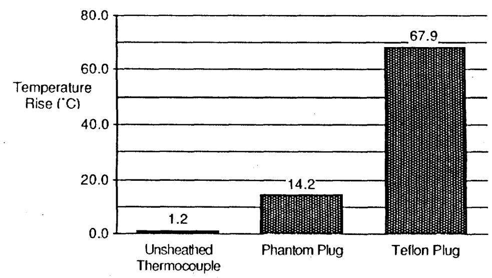

Fig. 1. Bar graph of heating trials comparing the temperature rise of the phantom plug to the Teflon plug.

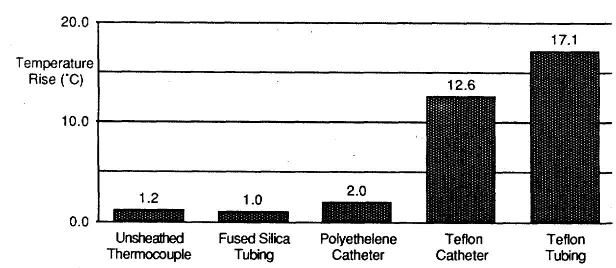

Fig. 2. Bar graph of heating trials comparing the temperature rise of the various sheathing materials tested.

Discussion and Conclusion

Our original intent was to contrast the absorption of Teflon sheathing material with that of the tissue it displaced. To simulate the tissue we used a phantom material with an ultrasonic absorption coefficient and speed of sound similar to muscle. As can be seen in Fig. 1, there was a significant difference in the heating of the probe surrounded by the Teflon as opposed to the probe surrounded by the phantom material. The diameter of the Teflon was smaller than that of the phantom while the lengths of the cylinders were identical. Thus, the ratio of surface area to volume was higher for the Teflon than for the phantom material, and it should cool more by conduction given comparable heating density. As seen in Fig. 1, this was not the case; the Teflon sample rose significantly higher in temperature. The major cause of this difference is probably due to the higher ultrasonic attenuation coefficient of the Teflon (0.24 per cm at 1.0 MHz) compared to the phantom material (0.13 per cm) [2]. Another factor involved is the thermal conductivity of the two materials. Teflon has a lower coefficient of thermal conductivity [0.399 W/(mK) at 300 K] than does a water-based gelatin such as the phantom [water: 0.609 W/(mK) at 300 K], tending to inhibit the conduction of heat from the core to the cooling surfaces more in the Teflon than in the phantom material. When placed in living, perfused tissue, the difference in thermal conduction between Teflon and the tissue it displaces will be even more pronounced.

Fig. 2 shows the results we obtained by heating sheathed probes of similar size. The unsheathed thermocouple exhibited a minimum of heating when subjected to the ultrasonic beam. The fused silica sheathing and the polyethelene catheter also showed small temperature rises when heated. When these three heating trials are compared to the two Teflon sheaths (the catheter and thin wall tubing), a large difference in the heating levels can be seen. Again, the Teflon materials showed a significantly larger temperature rise than the other materials tested.

Although limited in scope, this experiment showed dramatic evidence that the sheathing material used to protect the thermocouple cannot be neglected when the probes are being subjected to ultrasonic heating conditions.

References

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[2] P. K. Kuhn, "Ultrasonic beam shaping for localized hyperthermia," M.S. thesis, Dep. Elec. Eng., Univ. Utah, Salt Lake City, 1983.