2021 43rd Annual International Conference of the
IEEE Engineering in Medicine & Biology Society (EMBC)
Oct 31 - Nov 4, 2021. Virtual Conference

In-vivo Experiment Using a Miniaturized Probe of a Core Body Thermometer for Convection Changes

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***Abstract*—A miniaturized probe of a non-invasive core body thermometer was fabricated by optimization using parametric studies to minimize convection errors. It is robust against convection changes, based on *in-vivo* experiments for seven subjects with showing the measurement accuracy of ±0.2 °C.**

I. INTRODUCTION

Core body temperature (CBT) is the temperature of internal organs. Infection can be detected by a temporal increase in CBT. Circadian change of CBT reflects biological rhythms. Therefore, the goal towards advanced health management applications is to visualize circadian rhythms by continuous measurement of CBT. However, the current method is not convenient in evaluating CBT because it requires inserting a temperature sensor into the body cavity. The heat flux method has been proposed as an alternative, in which a probe with two temperature sensors is attached to the body's surface to estimate CBT based on the temperature difference (heat flux) [1]. However, this method undermeasure the heat flux due to heat loss around the probe caused by convection, resulting in CBT estimation errors. Therefore, a heat flux path control structure (HFPCS) that reduces heat loss during convection was proposed [2]. However, the HFPCS is large, so it is unsuitable for long-term measurement. Therefore, a miniaturized probe that can easily be worn on an adult forehead was designed by optimizing HFPCS using parametric studies. A fabricated probe was evaluated in an *in-vivo* experiment.

II. METHODS

The probe size was designed as Φ30xH5 mm. The top and the hole diameter of the HFPCS [3] are related to the heat loss because they affect the temperature distribution inside the body. They were optimized to minimize convection errors by parametric study using finite element method simulations (see Fig. 1 (a)). The fabricated probe is shown in Fig. 1 (b). The top and the hole diameters were 4 and 11 mm, respectively, and the assumed error was 0.02 ºC. The estimated CBT, T_{CBT}, is given by

$$T_{CBT} = T_1 + \alpha(T_1 - T_2) \quad (1)$$

T_1 and T_2 are the temperatures obtained from the probe, and α is a coefficient given by the initial calibration that includes the biological thermal resistance [4].

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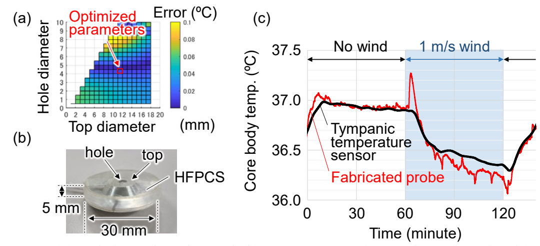

Figure 1. (a) Fabricated probe and (b) *in-vivo* experimental results of Subject 4.

Table 1. Average error from reference CBT at 1-m/s wind

Subject	#1	#2	#3	#4	#5	#6	#7
Average error (ºC)	-0.04	0.13	-0.11	0.12	-0.05	-0.19	-0.00
Standard deviation (ºC)	0.05	0.04	0.04	0.04	0.07	0.08	0.03

III. EXPERIMENT AND RESULTS

The probe was attached to the forehead of a subject seated in a resting position. The convection conditions were no wind and 1 m/s wind. The duration of each condition was 60 minutes. The tympanic temperature was measured as a reference of CBT. We conducted the experiment in an environmental chamber with an ambient temperature of 28 °C and a 50% relative humidity. We obtained valid data from seven subjects (healthy adult men and women). The experiment procedures were approved by the ethical committee of Waseda University and conducted according the Declaration of Helsinki. Figure 1 (c) shows an example of the experimental results. At the beginning of the experiment, it took 10 minutes for both the reference and the estimated CBT to reach a steady state. We observed a transient response immediately after the convection change at 60 and 120 minutes, but the temperature followed the reference thereafter. This transient response can be explained by the biological heat capacity. The trend was the same for all seven subjects. The average error from the reference CBT at a steady state of 1 m/s wind speed is shown in Table 1. The fabricated device achieved an accuracy of ±0.2 °C during the convective change.

IV. CONCLUSION AND DISCUSSION

We proposed a miniaturized non-invasive core body thermometer. The fabricated probe achieved an accuracy of ±0.2 °C during convective change. The difference in accuracy from the simulation may be due to the contact thermal resistance, which needs to be verified in the future.

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