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EVALUATION OF TEMPERATURE TRANSIENTS AT VARIOUS BODY TEMPERATURE MEASURING SITES USING A FAST RESPONSE THERMISTOR BEAD SENSOR

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Introduction

Body temperature monitoring of humans has been an important tool for helping clinicians diagnose infections, detect fever, monitor thermoregulation functions during surgical procedures, and assess post-surgery recovery.[1-3] Fever itself is typically not considered a disease. It is a response of the body to a disease, which is often inflammatory in nature. Elevation of the set point at the body temperature control center, the brain hypothalamus, is caused by circulating pyrogens produced by the immune system responding to diseases. Since the brain hypothalamus is not easily accessed by thermometers, other body locations have been identified as alternative measuring sites. Those sites include the pulmonary artery, rectum, bladder, distal esophagus and nasopharynx, sublingual surface of the tongue, under the armpit, tympanic membrane, and forehead.

A recent literature review[4] of the existing commercial over-the-counter medical thermometers suggested that the steady state temperatures at some measurement sites may deviate significantly from the true body core temperature. In addition, many manufacturers have implemented a so-called "fast mode" measurement to give a temperature reading within 6-10 seconds. The fast, predictive, mode uses an algorithm to estimate the thermal equilibrium temperature based on temperatures measured in the initial several seconds. The motivation behind the algorithm is to shorten the recording time, which provides convenience when dealing with small children. However, its accuracy is unknown, since it is unclear whether rigorous heat transfer analyses, incorporating conduction, convection, blood perfusion, as well as body's responses to the insertion of the temperature sensor, are implemented to derive the formula. Further, most of the previous studies have compared the readings of oral or axillary thermometers to a mercury thermometer at another site (either the pulmonary or the rectal site) to evaluate its accuracy. When a mercury thermometer is used at the same location, because of the thermometer's size, it can only be used to give the steady state temperature rather than the transient temperatures. Therefore, the mercury thermometer is unable to show how the steady state temperature is established.

The objective of this study is to evaluate how the temperature environment changes after insertion of a temperature sensor into true (mouth) and "pseudo" (armpit, palm) body cavities. A fast response thermistor bead temperature sensor is used to measure temperature transients at various body cavity sites. The sensor was used to determine how long it takes to establish a steady state and the deviation from the true body temperature. The information from this study can be used to understand whether a predictive algorithm can be derived and how thermoregulation in the body may affect its accuracy.

Methods

A temperature probe, i.e., a thermistor bead temperature sensor, was specifically designed for this study in collaboration with Alpha Technics (Irvine, CA). The probe works as a part of a commercially available temperature measurement system (T-View system, Alpha Technics, Irvine, CA). It has a nominal resolution of 0.001°C. Its response time, when immersed into a water bath, is less than 5 seconds due to its small size (< 0.8 mm dia.). The temperature measurements in various body cavities were performed in a healthy human volunteer in this preliminary study. The oral temperature recordings were measured by inserting the probe into the right or left sublingual pocket between the tongue and the mouth floor, due to the rich blood perfusion there. Two "pseudo" body cavities were used, one is at the axillary site by folding the arm at the armpit, and the other is by forming a fist. The temperature sensor is initially placed in a normal room environment (22-23°C) and then inserted into the body cavity. The measuring time was as short as 5 minutes or longer than 40 minutes to determine the steady state temperature. Temperatures were measured via software (T-View) provided by the company, at a rate of 7 times per second.

Results and Discussion

The response time of the sensor tested by immersing it into a water bath maintained at 37°C is given in Figure 1. All three repeated experiments give consistent results. The response time to reach the final steady state temperature of 37.045°C is approximately 5 seconds, and it takes less than 2.2 seconds to have an error less than 0.1°C (>36.945°C).

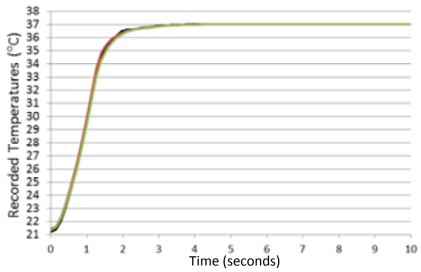

Figure 1. The recorded water temperatures by the thermistor bead sensor at the sites of the left and right sublingual pockets.

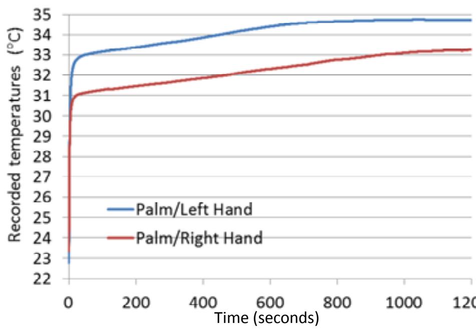

Figure 2. The recorded temperature transients by the thermistor bead sensor placed inside the palm.

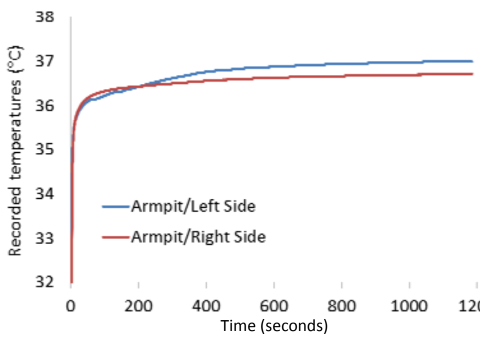

Figure 3. The recorded temperature transients by the thermistor bead sensor at the axillary sites.

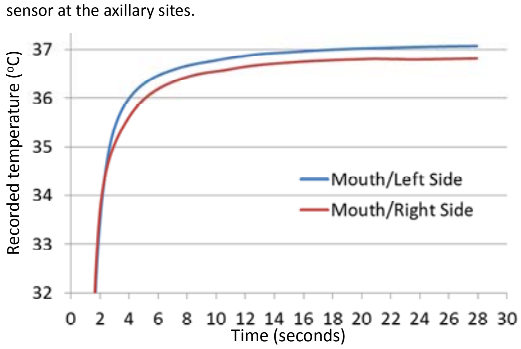

Figure 4. The recorded temperature transients by the thermistor bead sensor at the sites of the left and right sublingual pockets.

Figure 2 illustrates the initial fast response to the change of temperatures in the palm pseudo cavity, from the room environment to the warm palm skin. This is followed by gradual increase in the skin temperature, which may be attributed to the thermal environment change (open palm to closed palm) and blood perfusion increase in the palm region. The steady state temperature occurs at approximately 1200-1550 seconds (20-26 minutes) with the steady state temperatures far below 37°C (Left: 34.738°C, Right: 33.561°C).

As shown in Figure 3, the steady state temperature at the axillary site is much closer to 37°C, although there is a temperature difference between both sides. The left side established a steady state of 36.998°C at approximately 1174 seconds, while it took much longer (2410 seconds) for the right side to reach its steady state temperature of 36.860°C. Again, it seems that the local blood perfusion rate plays a significant role to induce a gradual increase in the temperature of the armpit skin in contact with the probe. In contrast, the probe registers the local temperature inside the mouth at a relatively fast pace. Figure 4 illustrates that it took 120-195 seconds to establish the steady state (left: 37.166°C, right: 37.002°C). Less than 20 seconds were needed to record the oral temperature if the inaccuracy was allowed to be 0.2°C.

Table 1 summarizes the recorded results and gives the realistic measuring time to achieve the given accuracy; it takes much longer to achieve the prescribed accuracy at the right sides than the left sides.

Table 1. Recorded time (in seconds) to establish steady state temperatures with deviations of 0.1, 0.2, and 0.3°C from the steady state temperature.

Deviation from the steady state	Mouth		Axillary		Palm	
	Left	Right	Left	Right	Left	Right
0.0°C	115	195	1174	2410	1030	1551
0.1°C	26	95	656	1535	779	1344
0.2°C	16	20	452	756	673	1265
0.3°C	12	13	354	401	618	1198

In summary, experimental studies were conducted to measure the temperature transients at various true and "pseudo" body cavities using a thermistor bead probe. The fast response time of the probe was confirmed by the experiments. The extremely long time to establish a steady state implies a gradual interference of the local blood perfusion rate at the measuring site. The results suggest that there is a potential difference between the steady state temperatures recorded at different measurement sites of the body, and the time required to reach steady state differs by two orders of magnitude, depending on the measurement site. Therefore, testing the fast predictive mode of the thermometers in a water bath is questionable.

Acknowledgment

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