A NEW METHOD FOR MONITORING DEEP BODY TEMPERATURE FROM THE SKIN SURFACE

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SUMMARY

1. A new technique for monitoring the deep body temperature is described. The technique depends on creating a zone of zero heat-flow across the body shell; this brings the deep body temperature to the skin surface where it is measured with a simple electronic thermometer.

2. The new device gives a temperature closely comparable with other methods for measuring the deep body temperature in the resting subject, and is simple to use and socially acceptable.

Key words: body temperature, patient monitoring, transcutaneous deep body temperature monitor.

An ideal site for measuring deep body temperature should meet the following three requirements (Cooper, Cranston & Snell, 1964). (1) Measurement should be convenient, harmless and painless. (2) Temperature at the site should not be influenced by local blood flow or by environmental changes. (3) Temperature changes at the site should reflect quantitatively and rapidly those small changes of arterial blood temperature which evoke vasomotor responses from the central receptors.

Existing techniques utilizing the body's natural orifices all fail to satisfy the first requirement during prolonged patient monitoring and especially in babies and small children.

In the technique described here, the deep body temperature is brought to the skin surface using a device that creates a region of zero heat-flow from the core across the body shell. We report tests assessing the accuracy of this deep body temperature monitor which has previously been the subject of a brief communication (Fox & Solman, 1971).

MATERIALS AND METHODS

The probe

This is constructed as a multi-layer sandwich using flexible materials which contour to the
body surface (Fig. 1). The probe has the dimensions 6 cm x 6 cm x 0.6 cm and contains two closely matched thermistors, a piece of nylon gauze and a thin-film heater element. The components are encapsulated in clinical-grade silicone rubber using a single vulcanizing process.

The control circuit

The two thermistors in the probe form two arms of a Wheatstone bridge, and the out-of-balance signal from the bridge operates a transistor switch in the probe heater-circuit through a comparator amplifier and a Schmitt trigger. The signal from the thermistor in contact with the skin is also fed through a measurement amplifier to the recording meter which is graduated in 0.1°C divisions over the range 29–42°C. The time to reach equilibrium is reduced to about 20 min by an automatic switch circuit which heats the probe to 37°C on initial application. The probe is applied to a suitable site on the trunk, such as the upper sternum, with a low skinfold thickness and a few large veins, using double-sided adhesive tape.

The transcutaneous probe temperature has been compared with the temperatures of the rectum using a thermistor thermometer; the intestine by temperature-sensitive radio pills (Fox, Goldsmith & Wolff, 1961); the external auditory canal using a thermistor thermometer and the insulated head technique (Bradbury, Fox, Goldsmith & Hampton, 1964). Skin temperature was measured from the mean of eight thermistor thermometers attached to representative body sites. The test situations have included exposure to a wide range of thermal environments with subjects resting and working, and during the induction of an artificial fever. The results of three such sets of experiments are briefly described below.

RESULTS

Experiment 1

Two male and one female subject were exposed to three climates with air temperatures of 15, 25 and 35°C and an air speed of 30 m/min with 40% relative humidity. The subjects were seated at rest facing the airflow dressed in minimal clothing (shorts, plimsoles and brassière for the female). Temperatures recorded after 45 min of exposure are illustrated in Fig. 2 for one of the male subjects. These results showed that the transcutaneous device will give readings closely comparable with those obtained by existing deep body temperature measuring techniques on the resting subject and is relatively unaffected by a wide range of skin temperatures.

Experiment 2

The response of the new device to a fever is of particular interest, because at the onset of
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fever, skin temperature declines while deep body temperature increases. An experiment was performed on one of us using the technique of intravenous injection of endogenous pyrogen (Fessler, Cooper, Cranston & Vollum, 1961). The subject was tested in the air-conditioned bed (Fox, Crockford, Hampton & MacGibbon, 1967) with the air temperature to the bed at 28°C. The temperature recorded from the transcutaneous device followed the other measures of deep body temperature closely, even while skin temperature was falling (Fig. 3).

![Figure 2](image-url)  
**Fig. 2.** A comparison of the deep body and skin temperatures (°C) of a subject after 45 min of exposure to three environmental temperatures. △, Transcutaneous probe sited on upper sternum; ▲, transcutaneous probe sited on lower chest region; ○, left-ear temperature; ◻, skin temperature. These symbols are placed at the ends of the lines they designate, and all of the points are shown as ●.

**Experiment 3**

During preliminary tests with working subjects it was noted that the device appeared to give less satisfactory results on the working compared with the resting subject. An experiment was therefore devised to compare the temperatures recorded while the subject was walking at two different speeds on a treadmill (753 kJ/h and 1756 kJ/h) in three different thermal environments (Climate I: dry bulb (DB) = 29-0°C, wet bulb (WB) = 17-2°C, air speed (AS) = 76 m/min; Climate II: DB = 24-0°C, WB = 13-7°C, AS = 76 m/min; Climate III: DB = 17-0°C, WB = 8-9°C, AS = 76 m/min). The subject was dressed in shorts, plimsoles and insulated headgear. The three climates were tested on consecutive days with the slow walk for 1 h preceding the fast walk for 1 h on each occasion. The temperatures recorded at the end of each hour are illustrated in Fig. 4.
Fig. 3. A comparison of the deep body temperatures and skin temperatures (°C) during the induction of an artificial fever. △, Transcutaneous probe sited on upper sternum; ○, left-ear temperature; ■, right-ear temperature; ●, temperature sensitive radio pill; ○, skin temperature. P, time of injection of pyrogen.

Fig. 4. A comparison of the body temperature (°C) measured after 1 h of 'slow' and 'fast' walking in three environmental temperatures. △, Transcutaneous probe sited on upper sternum; □, left-ear temperature; ■, right-ear temperature; x, temperature-sensitive radio pill; ●, rectal temperature; ○, skin temperature.
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The agreement between the body temperatures was good in the warmer climate (I) at the slowest speed, but at the higher walking speeds and especially in the cooler climates (II and III) deep body temperatures measured by the radio pill and rectal probe increasingly diverged from the transcutaneous probe with the ear temperature occupying an intermediate position. These results confirm that the device is likely to prove less satisfactory in the working compared with the resting subject and when the temperature gradient across the skin of the body is high compared with low.

DISCUSSION

Deep body temperature is frequently measured from self-insulating sites close to large vessels such as the axilla or groin in babies and small children, when rectal or oral measurements present some difficulty. The method described utilizes the same principle but makes it much more reliable.

The results obtained with the new device from resting subjects were very encouraging. The temperature was usually a little lower than the other deep body temperatures measured, but the response to a change in deep body temperature was rapid and the temperature was relatively unaffected by differing levels of skin temperature.

When the subjects were working and exposed to a cool environment the results were less satisfactory, but these conditions would be abnormal in most clinical applications.

It is also generally accepted that there are differences between the temperatures recorded from the currently used sites and these differences can be influenced by activity and environmental conditions. Rectal temperature is usually one of the highest in the body and above intracardiac temperature in the resting subject (Eichna, Berger, Rader & Becker, 1951). The temperatures measured in the great vessels, oesophagus and at the tympanic membrane usually fall between the high values found in the rectum and the lower values found in the mouth (Minard, Copman & Dasler, 1964). Tanner (1951) found rectal temperature was on average 0.45°C higher than mouth temperature. The rectal site suffers from the disadvantage of marked thermal inertia so that its temperature can fall below those in the mouth, oesophagus and at the tympanic membrane during rapid body warming (Minard & Copman, 1963; Minard et al., 1964). The difference between the temperatures in the mouth and rectum has also been found to increase from 0.5°C with subjects in a thermally neutral environment to 1.0°C on exposure to cool conditions (Fox, Woodward, Fry, Collins & MacDonald, 1971).

Theoretical considerations and preliminary experiments with probes of different surface areas both suggest that larger area probes would prove more accurate in disadvantageous physiological situations. However, increasing probe size involves difficult technological problems of achieving greater probe flexibility and ensuring the essential zero heat-flow relationship over a larger surface area. These problems are not insuperable, but we believe the present probe size represents the best available compromise between the requirements of accuracy, simplicity and cost.

We consider the performance, subject acceptability and simplicity in use of this device should commend it for many clinical applications requiring long periods of temperature monitoring. On theoretical grounds it seems likely to prove especially suitable for use in intensive care units, and for monitoring body temperatures in small babies and young children; this use, however, will require formal validation.
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REFERENCES


