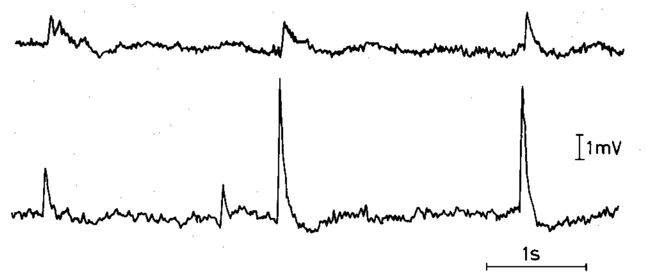

Fig. 1 *'Spontaneous' synaptic activity, intracellularly recorded from two L neurones in the buccal ganglion of Aplysia and sampled at 100 Hz per channel*

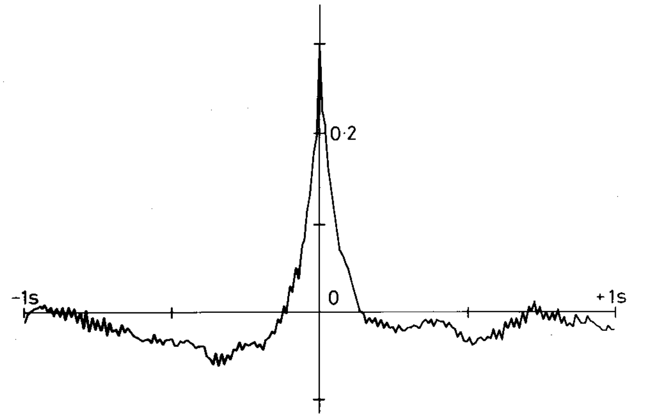

Fig. 2 *Normalised cross-correlation histogram evaluated from the 'spontaneous' synaptic activity from two L-neurones. A part of the signals is shown in Fig. 1*

used together with an acquisition system described in a previous paper (RICCI and FIORE, 1987). Both were managed by a Basic program, which also provided data display and storage.

Details on the subroutine are available on request to the authors.

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Technical note

Improved probe for a deep body thermometer

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Keywords—*Body temperature, Deep body thermometer, Sublingual temperature, Zero heat-flow method*

Med. & Biol. Eng. & Comput., 1988, **26**, 456–459

1 Introduction

A METHOD FOR the transcutaneous measurement of the internal temperature by creating a zone of zero heat flow across the body shell was proposed by FOX and SOLMAN (1971). TOGAWA *et al.* (1973) then modified a thermometer using the same principle as that of Fox and applied it to human subjects to measure deep tissue and local temperatures. However, these thermometers did not adequately measure temperature. We therefore have further modified the thermometer to increase its performance in the measurement of temperature. In addition, we further simplified the electric circuit of the thermometer.

The present communication describes a modified probe, thermometer performance and a comparison of the sublingual temperature with the deep body temperature measured by this thermometer.

2 Principles and methods

A schematic drawing of the servocontrolled thermal insulation technique is shown in Fig. 1. The device has two thermal sensors separated by a layer of heat-insulating material and an electrical element mounted at the rear of the device. The sensors detect the heating layer and skin surface temperature. The sensors' output signals are compared by a differential amplifier output, as an error signal, and used to control the heater current in such a way as to

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First received 17th July 1987 and in final form 14th March 1988

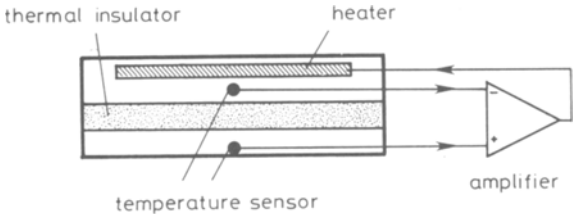

Fig. 1 *Schematic diagram showing a cross-section of the deep body thermometer probe and control circuit*

achieve a situation in which no temperature gradient arises across the insulating layer and thus no heat flows out through this layer. This technique is known as the zero heat flow method. The device satisfies the zero heat flow condition as long as it contains an ideal heat insulator. This prevents heat loss from the skin surface beneath the device and makes the skin surface equilibrate with the tissue temperature. Thus the subcutaneous tissue temperature can be measured by the lower thermal sensor which is in contact with the skin surface.

An improved probe is shown in Fig. 2. The probe outside is covered with a thick aluminium cup and its inside space filled with a soft polyurethane foam heat insulator. The circumferential guard is maintained isothermally to the probe centre by the servocontrolled heater circuit which is driven by the thermal sensor. The complete probe is 45 mm in diameter and 13·5 mm thick. It contains an electric heat (nickrome wire of 0·1 mm in diameter, about 100 Ω), thermal sensors and the servocontrol circuit. The heater is fixed at the periphery so as to sandwich the thermal insulator between the heat and the frame of the probe. Of the three thermal sensors (AD 590), one is placed in the periphery of the frame and the others are fixed on the centre plate which is suspended with the soft polyurethane foam. Two sensors placed on the centre plate are used for the servocontrol and for measuring the skin surface temperature. The probe surface contact which is in the skin is covered with a vinyl sheet so as to minimise the probe–skin distance.

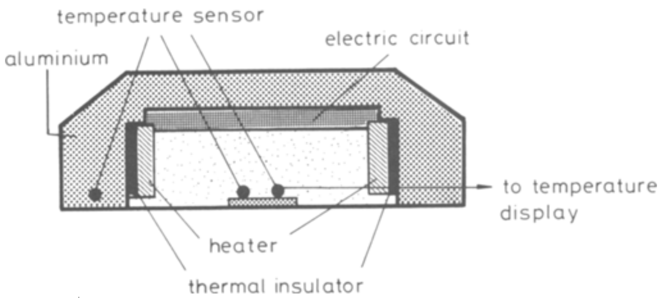

Fig. 2 *Diagrammatic cross-sectional view of the modified probe showing the temperature sensor, heater and thermal insulator*

Fig. 3 shows the circuit used for the thermometer. This circuit comprises three temperature sensors, a differential amplifier, a potentiometer and a power transistor. The potentiometer was adjusted to a threshold level at which the heater current begins to change when the probe is placed in a thermostatically controlled water bath (37°C). The temperature difference and temperature signals are amplified independently. The temperature difference signal controls the heater current so that the frame temperature is equated to the temperature of the plate in contact with the skin. However, the heater is at a slightly higher temperature than the centre of the probe, due to the sandwiched thermal insulator. For this reason, the heater temperature has an effect which increases towards the centre of the probe, and its effect depends on the thickness

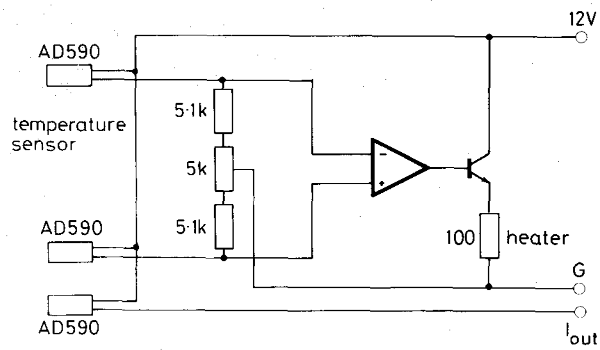

Fig. 3 *Electric circuit of the temperature difference amplifiers, the potentiometer and the three temperature sensors assembled in the probe*

of the sandwiched thermal insulator. In this probe, the thickness of the sandwiched thermal insulator is adjusted in such a manner that the detecting error of the thermometer is minimised. There is therefore positive feedback to the temperature sensor at the centre of the probe. Temperature measurement is achieved by the sensor placed on the central plate, and a signal corresponding to the temperature is sent via a cable to the temperature display.

2.1 *Simulator experiment*

The simulator experiment consisted of using a layer of constant temperature and a heat transfer layer that had some thermal resistance. Fig. 4 shows the structure of this experiment. The water temperature is equivalent to the deep tissue temperature and the rubber thickness is thermally equivalent to the heat transfer layer of the human body. A box (250 × 200 × 50 mm) was made of copper plate and immersed in a thermostatically controlled water bath. A rubber sheet was placed on the bottom of this box. The probe was then placed on this sheet, and the measured temperature was continuously recorded by a microcomputer. Each rubber sheet was 1–10 mm thick (see below) with a heat conductivity of $5{\cdot}4\,\mathrm{kJ\,m^{-1}\,h^{-1}\,{}^{\circ}C^{-1}}$.

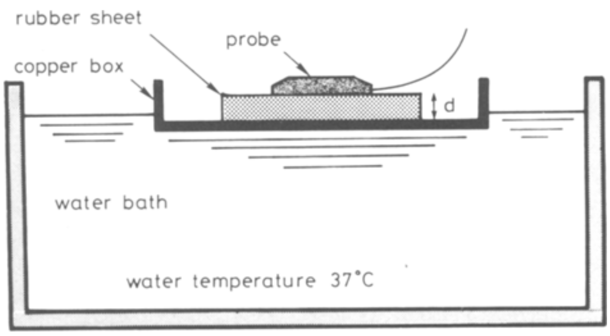

Fig. 4 *Schematic diagram of a simulator experiment*

Vaseline was applied to the space between the copper, the rubber sheet and the probe to achieve good thermal contact.

In a temperature- and humidity-controlled room, with the room temperature set at 20°C or 25°C and the water temperature of the thermostatically water controlled bath at 37°C, a rubber sheet was placed on the copper plate without any probe placed on the rubber sheet. After the rubber sheet reached thermal equilibrium, a probe was placed on it and the temperature was then recorded by a pen recorder.

2.2 *Comparison with the sublingual temperature*

Deep tissue temperature measurements obtained with the probe were compared with the sublingual temperature in 21 male and 22 female subjects. The subjects were seated on a chair in a room with an ambient temperature of 20°C or 25°C and a relative humidity of 60 per cent. The probes were fixed on the forehead and temple region with a hair-band. Sublingual temperature was measured by using a temperature electric sensor (AD 590). The sensor was placed beneath the subject's tongue. The transmitting cable connecting the sensor to an operation amplifier consisted of a fine stainless-steel wire (length 300 × 0·05 cm in diameter), so that the sublingual temperature could be measured without the influence of ambient temperature. The sublingual, forehead and temple temperatures were simultaneously fed into a microcomputer via a 12-bit A/D convertor.

3 Results

Fig. 5 presents the relationship between the thickness of the rubber sheet and the error (which is the difference between the final equilibrium temperature and the water temperature). At a room temperature of 25°C, the deep temperature could be measured from the surface of a rubber layer 10 mm in thickness with an error of less than ±0·1°C. At a room temperature of 20°C, the error was within 0·1°C for a rubber thickness of less than 9 mm. The response time was less than 20 min.

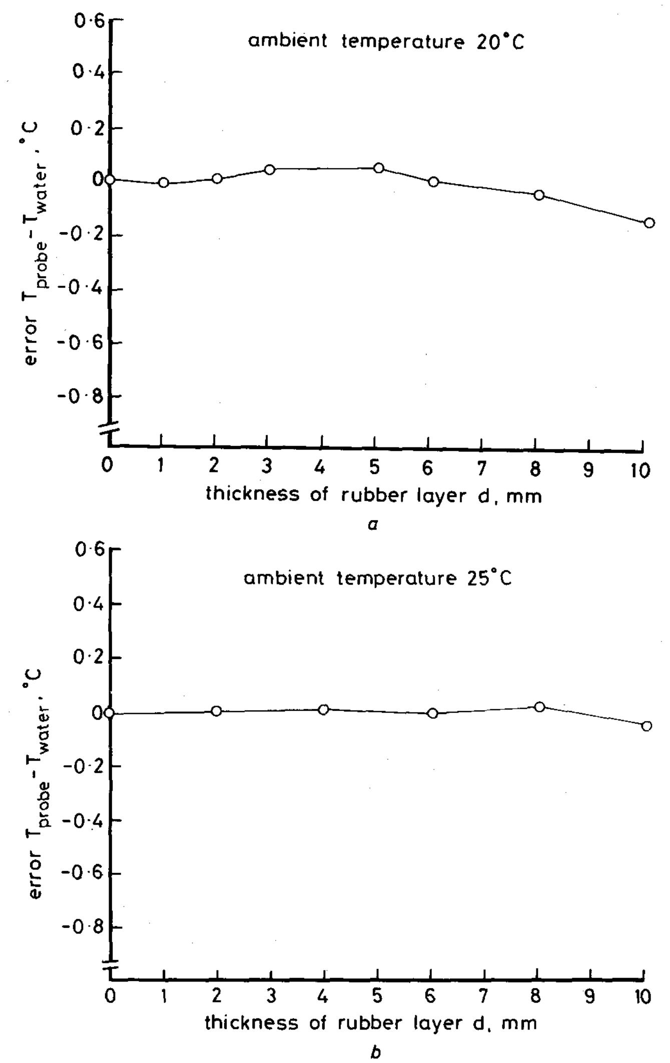

Fig. 5 *Relationship between the thickness of the rubber layer d and the error signal, which is the difference between the final equilibrium temperature T_{probe} and water temperature T_{water}*

At a rubber thickness of 2–4 mm, the time required for the difference between the two temperatures to become less than 0·1°C was 6–7 min, whereas at a rubber thickness of 10 mm it was about 20 min.

Table 1 shows mean values and standard deviations of the deep tissue temperature measured by the thermometer and sublingual temperatures obtained in 21 males and 22 females at room temperatures of 20°C and 25°C. For both the male and female groups, the difference between the mean deep tissue temperature measured on the forehead, right temple or left temple and the sublingual temperature was within ±0·1°C. The difference between the forehead and sublingual temperature was not significant ($p < 0·05$). The difference between the right temple and sublingual temperature was also not significant ($p < 0·05$).

4 Discussion

Deep body thermometers with a servocontrolled heating probe allow measurement in principle of the deep tissue temperature without ambient temperature effects (Kobayashi *et al.*, 1975). However, they are affected slightly by ambient temperature, and the degree of influence varies according to the structure of the probe and temperature control. Two types of probe have hitherto been reported: one developed by Fox *et al.* (Fox and Solman, 1971; Fox *et al.* 1973) and the other by Togawa *et al.* (1973; 1976). The probe developed by Fox *et al.* is reported to have the problem of incomplete heat insulation. The probe developed by Togawa *et al.* is surrounded with a metal of high thermal conductivity to maintain the temperature of the circumference equal to that of the centre so that outward heat flow is prevented. This thermometer has sufficient accuracy for measurement in clinical situations; however, its performance is still slightly affected by the ambient temperature.

In the probe described in this note we have made the following modifications to solve the above-mentioned problems:

(*a*) the temperature sensor for servocontrol was fixed in the periphery of the frame to maintain the temperature of the circumference equal to that of the centre
(*b*) a heater was also placed on the thermal insulator, on the periphery of the frame
(*c*) positive feedback in the servocontrolled heating was applied between the centre and the frame of the probe.

Using this configuration, the thermometer could measure the deep tissue temperature without being influenced by ambient temperature.

In a simulator experiment at a room temperature of

Table 1 Comparison of the sublingual temperature and forehead temperature, right temple temperature and left temple temperature measured with the deep body thermometer

	Number of cases	Room temperature, °C	Forehead temperature, °C	Temple Right temperature, °C	 Left temperature, °C	Sublingual temperature, °C
Male	21	20	36·88 ± 0·16	36·9 ± 0·23	36·94 ± 0·22	36·92 ± 0·21
Male	21	25	36·83 ± 0·13	36·8 ± 0·22	36·86 ± 0·22	36·84 ± 0·22
Female	22	20	36·97 ± 0·17	36·96 ± 0·17	36·97 ± 0·17	36·98 ± 0·15
Female	22	25	36·94 ± 0·17	36·88 ± 0·22	36·95 ± 0·2	36·88 ± 0·18

20°C this probe could measure the deep temperature from the surface of a rubber layer 9 mm in thickness with an error of less than ±0·1°C. At a room temperature of 25°C, the thermometer could measure the deep temperature from the surface of the rubber layer 10 mm in thickness with the error less than ±0·1°C. In this study, the temperature readings were slightly higher (for a rubber thickness of 3–5 mm) than the deep temperature, owing to the influence of the positive feedback method.

The sublingual temperature is the most frequent measurement made in hospital and general practice, and a reliable index of deep body temperature. ILSLY *et al.* (1983) showed that sublingual temperature is lower by 0·4°C than blood temperature in the pulmonary artery. However, there are few comparative studies comparing the sublingual temperature and other deep body temperatures using a deep body thermometer. In previous comparative studies TOGAWA *et al.* (1976; 1979) showed that the mean occipital temperature measured with this type of thermometer was 36·88°C, compared with a mean rectal temperature of 36·77°C. Forehead temperature was also compared with blood temperature in the internal jugular vein, as measured with a catheter thermometer (TSUJI *et al.* 1976). The forehead temperature reading was 37·8 ± 0·5°C while the blood temperature was 37·7 ± 0·4°C. In this present experiment, we have compared the sublingual temperature with deep tissue temperature measured at the forehead and bilateral temples. The difference between mean sublingual temperature and mean deep tissue temperature at each site was within ±0·1°C.

This result indicates that this deep body thermometer can be used to continuously measure the deep body temperature as a body temperature monitor.

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