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Body Temperature Measurement of Domestic Animals

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Abstract

Various kinds of thermometers have been developed for practical uses in clinical and physiological measurements. Most of them, however, do not fully satisfy all the requirements in body temperature measurement. An electronic thermometer makes use of a thermistor or PN junction sensor to measure body temperature. In addition, a crystal and thermocouples are applied for the thermometer. On the other hand, several kinds of infrared detectors, such as thermal, photoconductive or photovoltaic detectors, have been developed and applied in radiation thermometer and thermograph system. As a noninvasive measurement method, a zero heat flow thermometer has been developed for measuring temperature in the central parts of animal body. In monitoring animal body temperature continuously a conventional measurement system is not suitable for such regions as rectum, vagina and tympanum for a longterm use. However, a zero heat flow thermometer can be used regardless of sex or region for animal body temperature measurement. The radiation thermometer in animal use has been considered accurate enough for use as a medical thermometer. The measuring region of skin temperature is limited only to the body without hair covering its skin surface. This paper presents techniques for measuring body temperature and discusses the electronic thermometer for the use in animals.

Discipline: Animal industry
Additional key words: electronic thermometer, temperature sensors, thermograph, zero heat flow thermometer

Introduction

The temperature of a living body varies with region and there is a fundamental difference between the temperature of core of the body and that of its periphery. The temperature measurements of the body are often intended to estimate representative temperature of the core and the peripheral zone of the body, even though both core and peripheral temperatures are not uniform.

Fig. 1 shows a simplified model[18] that is heat transport from the core to peripheral zone of the body. The heat produced in the core is transported to the peripheral zone by conduction and circulation convection. Circulation heat transport is adjusted by vasomotor control of the peripheral circulation to regulate effective body insulation. The temperature regulating system of the body stabilizes the core temperature by sensing it and thereby adjusting heat production and heat transport.

Although the mechanism for sensing body temperature is complex and not well understood, it is widely accepted that the receptors of temperature are concentrated in the hypothalamus. Thus, in thermoregulatory studies, the method with which core temperature is measured must accurately reflect hypothalamic temperature.

Tympanic temperature is regarded as a reliable index of the core temperature[2], although temperature of many different sites has also been used for practical purposes.

Thermometers used for core temperature measurements are generally required to cover a temperature range from 35 to 42°C. Physiological and pathological temperature variations generally occur within this range, which varies from the lowest temperature in the early morning or cold weather to the

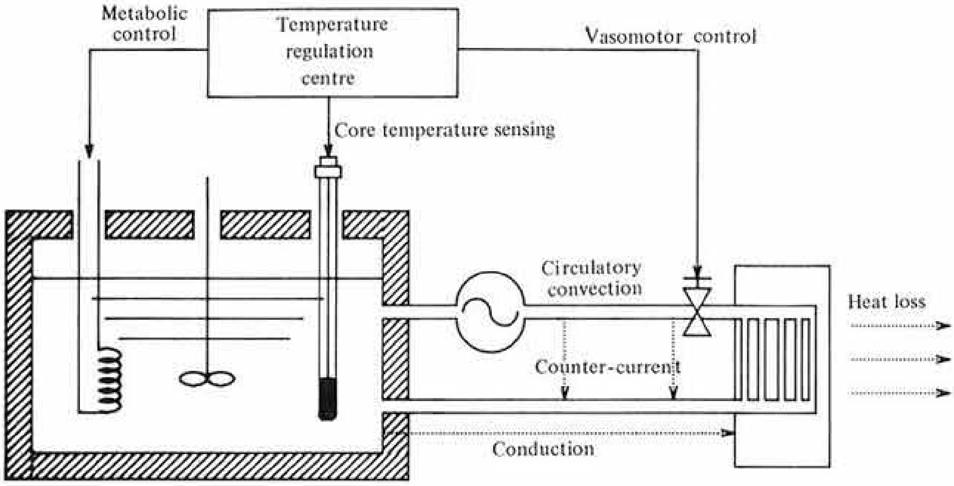

Fig. 1. Simplified model of thermoregulation of the body

highest one during febrile diseases or hard exercises.

The temperature of the skin varies at least between ambient and core temperatures. The skin temperature may vary much more widely in the heat and core stress test. Thermometer for skin temperature measurement should therefore have a wider range, e.g. 0–50°C. Although a higher resolution within a narrower range is also required in some cases.

Local temperature measurements in organs and tissues are also required in physiological studies and clinical examinations. At thermal equilibrium, the temperature of a tissue is determined by local heat production and heat transport into and from the site. Metabolically active organs and tissues have higher temperatures than other sites and can maintain temperatures higher than that of arterial blood. However, when the temperature of the tissue increases to a level higher than that of arterial blood, the blood cools the tissues. To increase metabolism in the tissues, the oxygen supply from arterial blood has to be increased; thereby, the cooling effect of the arterial blood is enhanced. A simple calculation shows that the increment of temperature in metabolically active tissue is not greater than 1°C, except when an effective counter-current heat exchange exists between arteries and veins, as seen in many animals[15].

The thermometer has to provide high resolution with a narrow temperature range. The normal temperature of calf and pig is 38.5°C and 39.0°C, respectively[9]. Therefore, the measuring range should be 35–42°C and absolute accuracy should be within 0.1°C. In the case of skin surface, the measuring range should be 0–50°C. In this study, a new method for body temperature is proposed.

Temperature sensor

There are many kinds of temperature sensors which are presently available for a thermometer. This means that there is an alternative choice of sensors in any case of measurement.

1) Thermistors

A thermistor is most widely used for thermoresistive sensors. It has a large temperature coefficient of about −4%/°C for the body temperature range, which is about 10 times larger than that of metallic thermoresistive elements. A thermistor, which was made by Edwards[4], is convenient for obtaining high resolution having a simple electronic mechanism with relatively narrow stability, i.e. 10^{-4}°C over 100 days. Non-linearity in temperature resistance can be adjusted by adding a fixed resistor so that the departure from linearity is less than 0.03°C in a varying range of 20°C. Thermistors can be equalized for interchanged probes by adding two fixed resistors. Differences, between those probes can be reduced to the level of about 0.05% or 0.01°C in temperature range of 10°C by using appropriate thermistors.

2) Thermocouples

A thermocouple is a thermoelectric sensor under wide uses at present. It provides an electromotive force between two junctions, the magnitude of which is proportional to the temperature difference. Although the electromotive force may not be linear in a wide range of varying temperatures, departure from the linearity is generally small within the temperature range used in medical thermometry and the errors are compensated with commercial thermometers. The errors caused by temperature fluctuations of the reference junction are about 0.05°C with an ice bath and about 0.2°C with an electronic reference temperature compensation. Variations in sensitivity in commercial thermocouple are about 0.5 and 0.25% for copper-constantan and platinum-rhodium thermocouple, respectively. An overall accuracy of about 0.3°C is easily attained by commercial thermometers without any individual calibration for each thermocouple.

3) PN junction diodes and transistors

The temperature coefficient of the voltage across a PN junction, through which a constant current flows, can be used as a convenient temperature sensor. Ga, Si and GaAs PN junctions have been studied by MacNamara[13], Cohen et al.[3]. The temperature coefficient is about 2 mV°C, which is about 50 times larger than that of a copper-constantan thermocouple. Non-linearity is not serious and can be adjusted. The error is less than 0.05°C within a range from −50 to +100°C. The stability of the temperature readings during a period of several months is 0.04°C. Variations between sensors are less than 0.1% at room temperature[5]. An integrated circuit temperature sensor converting the voltage across the PN junction into a current output has been developed[16] and is now commercially available. The sensor is a two-terminal device, providing a current output proportional to absolute temperature (1μ/AK) for a supply voltage of 4–30 V. The error at 25°C is less than 0.5°C and long-term drift is less than 0.1°C per month in the model with the hightest performance (Analog Device AD 590). When a current to voltage conversion resistor is connected in series to that device, the resistor can be trimmed so that the calibration is zero at any desired temperature.

4) Crystal resonators

A quartz resonator with a suitable cut has a temperature coefficient of about 35 PPM/°C at resonant frequency. At 28 MHz the variation at resonant frequency is about 1,000 Hz/°C. Although temperature resolution is limited by the stability of the resonator, a short term stability of 5×10^{-6}°C is possible[7]. A commercial quartz thermometer has a temperature resolution of 10^{-4} with an absolute accuracy of 0.04°C from −80 to +250°C (Hewled-Packard 2804A). The availability of accurate temperature output expressed as a frequency is expected to be advantageous in digital signal processing.

Thermometer and probe

An electronic thermometer makes use of a thermistor or PN junction sensor to measure body temperature. A thermistor is also used widely in probes to detect temperature, where various types of thermistors are available according to the purposes of measurement. The rectum and vagina temperature probes are of a catheter type. In measuring inner bladder temperature, the thermistor is mounted at the top of the urethral catheter.

Zero heat flow method

Deep tissue temperature can be measured non-invasively from the skin surface, if heat flow across the skin is reduced to zero, thereby skin surface temperature is equilibrated with deep tissue temperature. The zero heat flow condition may be obtained with an ideal thermal insulator. However, the thermal insulators available at present, such as nylon wool or sponge rubber, are far from ideal. Fox and Solman[6] introduced an electronic servo-control system to achieve a complete thermal insulator, which enabled to measure deep temperature from the intact skin surface.

The probe and servo-control circuit of the zero heat flow thermometer are schematically shown in Fig. 2. The probe has two thermistors separated by a thermal and an insulator with an electric heating element at the rear of the probe. The temperature difference across the insulating layer is detected, and an error signal, if any, controls the heater current in such a way that no temperature gradient exists across the layer. The temperature measured by the

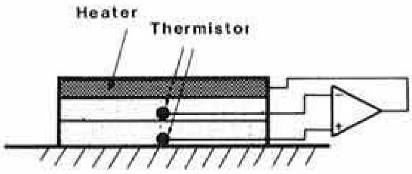

Fig. 2. Schematic diagram of the probe and the servo-control system of the zero heat flow thermometer

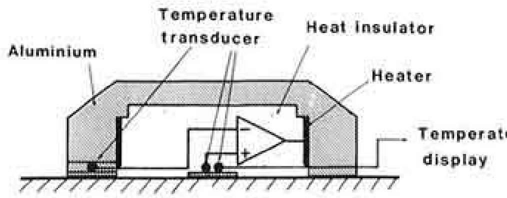

Fig. 3. Diagrammatic cross-sectional view of the modified probe showing the temperature sensor, heater and thermal insulator

lower thermistor attached to the skin is expected to be equilibrated with the deep tissue temperature. A complete unit having this system is now commercially available (Deep Body Thermometer Ltd.). The probe of the thermometer is a flat pad of 6 × 6 cm in size.

A modified probe covered with a thick metal guard was devised to minimize transverse heat flow from the center of the probe to the periphery. It is confirmed that this modification increases the accuracy of measurements[17]. An additional modification of probe with a simplified electric circuit of the thermometer was developed by Nemoto et al.[14], which is now under commercial production (Terumo Co.) (Fig. 3).

The zero heat flow thermometer has been widely used in human bodies, while no information on its animal uses has been reported. However, many investigators have recognized its resolution through comparisons with conventional body temperature measurements. Togawa et al.[17] presented temperatures measured by a zero heat flow probe, monitoring internal temperature changes within an error of 0.2°C through measurement with a thermocouple. Kobayashi et al.[11] reported that the temperature of a rubber bladder implanted in the abdomen of a dog, through which warm water was circulating, could be measured with an error of 0.1°C by a zero heat flow probe placed on the abdominal wall. On the other hand, Tsuji[19] showed that the mean forehead temperature in human bodies measured by the Terumo standard probe was 0.2 ±0.5°C lower than the mean pulmonary arterial temperature measured by a Swan-Ganz thermodilution catheter. Leeds et al.[12], using also the Terumo probe in hyperthermia therapy, observed that the forehead temperature readings were highly correlated with the pulmonary arterial temperature ($r: > 0.98$) within a range of 37–42°C. These studies confirm that the zero heat flow thermometer is useful for monitoring body temperature in animals.

Measurements of deep tissue temperature of a calf's forehead were taken for 24 hr with a zero heat flow thermometer. As presented in Fig. 4, the forehead temperature measured by the zero heat flow thermometer and the vagina temperature are close to each other with a parallel variation. The vagina temperature rose remarkably after the calf drank hot milk and the forehead temperature showed a similar tendency. The results of deep tissue and vagina temperature readings are summarized in Table 1.

The deep tissue temperature readings were highly correlated ($r: > 0.98$) with vagina temperature readings. The mean difference between the deep tissue and vagina temperatures was less than ±0.2°C. This shows that the zero flow thermometer can continuously measure deep tissue temperature of a calf for a long period of time.

The response time of zero heat flow measurement is 15–20 min when the probe is applied to the bare skin of the head or torso. However, under a temperature regulation system, changes in core temperature were not so rapid that a zero heat flow thermometer could not adequately follow them.

From these observations, it may be concluded that the heat flow measurement at the forehead of the torso is a reliable monitor or core temperature in most clinical situations, except the case of rapid cooling or warming. This technique may be suited particularly for long-term monitoring of body temperature.

Non-contact measurement method

A radiation thermometer is useful for non-contact temperature measurement, particularly for skin

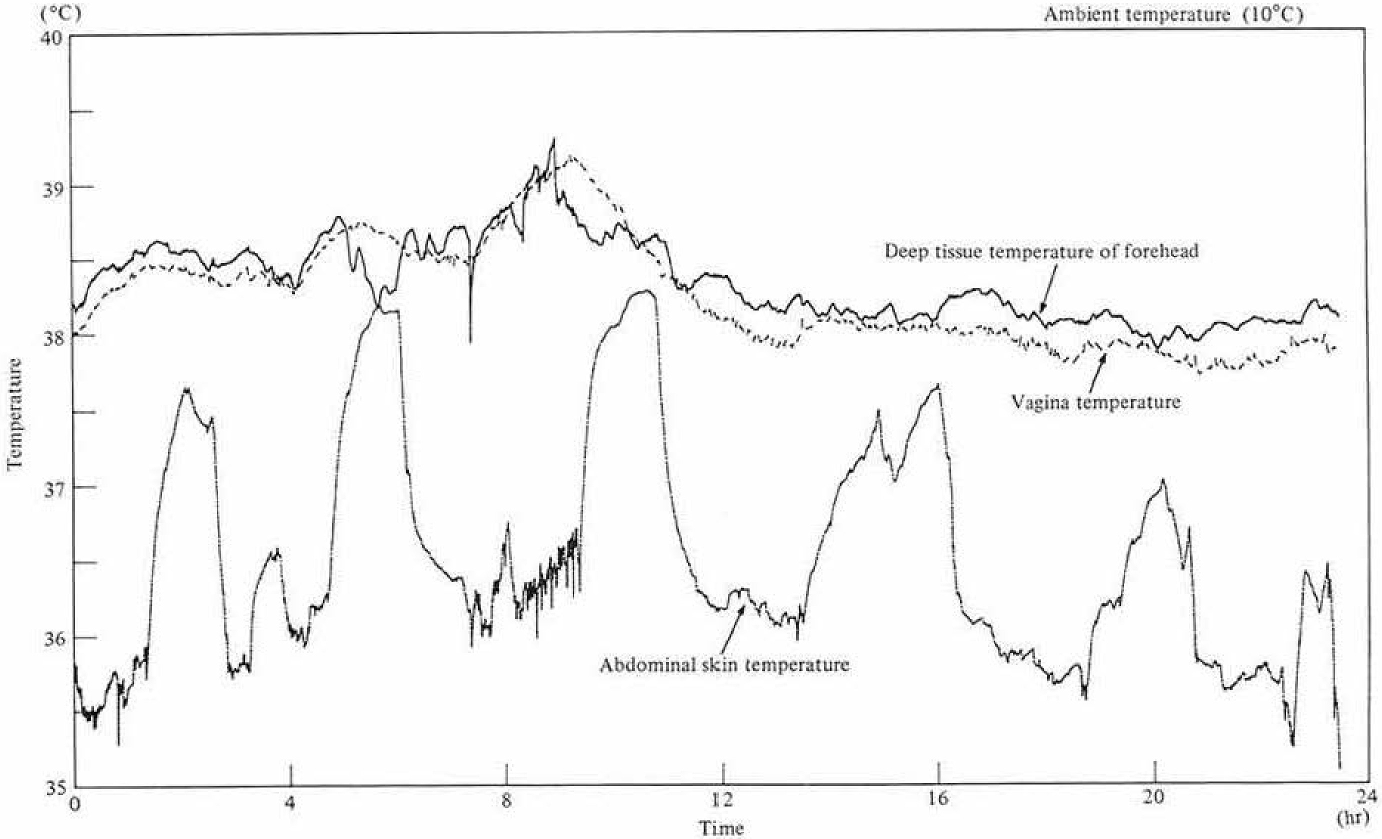

Fig. 4. Recording of the vagina temperature, the deep tissue temperature of the forehead and the abdominal skin temperature measured for 24 hr

Table 1. Comparison of the vagina temperature and the deep tissue temperature, the skin temperature for day time of 12 hr and night time of 12 hr

Room temperature (°C)	Time	Vagina (°C)	Deep tissue (°C)	Skin (°C)
10	Day	38.7 ± 0.19	38.5 ± 0.2	36.9 ± 0.71
	Night	38.3 ± 0.19	38.2 ± 0.2	37.0 ± 1.09
20	Day	38.9 ± 0.26	38.9 ± 0.2	37.5 ± 0.3
	Night	38.7 ± 0.13	38.5 ± 0.14	37.1 ± 0.35
30	Day	39.2 ± 0.17	39.2 ± 0.1	38.7 ± 0.35
	Night	39.1 ± 0.17	39.0 ± 0.16	38.7 ± 0.25

temperature measurement. The term thermograph is generally used for determining temperature distribution on the surface of a body.

If the object surface can be regarded as a black body, any correction of temperature readings due to ambient radiation is not necessary when a radiation thermometer is used, because the reflectance of a black body is zero. Skin emissivity on human bodies[8,20] is $0.94 > e > 0.98$ with some variations according to the part of bodies. In animal bodies, skin emissivity of pig is 0.955[10], that of cow is presumed to be almost the same as that of pig. This shows that animal skin's emissivity varies within the range in human bodies. The emissivity of wool as body hair is 0.78[1].

The conventional medical thermograph system employs mechanical scanning with an excellent performance by means of mirrors moving vertically and horizontally and a cooled HgCdTe or InSb infrared detector. A temperature resolution of 0.05°C is attained in commercial thermograph units. The field of measurement can be changed by adjusting the distance between the object and the camera in an appropriate range of focusing. Close-up investigations on a small area of less than 1 cm^2 can be practiced by using a wide-angle lens and an extension tube (Aga). The thermal image is displayed on a CRT screen as either discrete temperature levels presented by colors or a continuous gray tone. Color imaging allows quantitative assessment throughout the entire temperature range, while the gray tone image provides a clear picture, which is much more accurate for the identification of vascular changes.

Conventional thermograph units have an internal temperature reference so that radiation from the object can be compared with that from the reference body at every line scan.

Conclusion

The electronic thermometer provides electronic signal outputs, through which trend display, data storage or on-line data processing together with other physiological signals can be obtained with the aid of a microcomputer.

In monitoring body temperature continuously, a conventional measurement system is not suitable for such regions as rectum, vagina and tympanum for a long-term use, and the vagina is restricted to females. However, a zero heat flow thermometer can be used regardless of sex on region for body temperature measurement.

The radiation thermometer has been considered accurate enough for use as a medical thermometer. It should however be noticed that there still remain some sources of errors due to special properties of the skin in the inferred waveband, which is used by that method. Emissivity and penetration depth at a wavelength of around 10 μm have not been extensively studied *in vivo*, although it is always assumed that the emissivity of the skin is uniform and the penetration depth is practically zero. In animals, skin emissivity is within the range of humans. However, the measuring region of skin temperature is limited only to the body without hair covering its skin surface.

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