J Anesth (2002) 16:354–357

Journal of
Anesthesia

Evaluation of a newly developed monitor of deep body temperature

Michiaki Yamakage, Sohshi Iwasaki, and Akiyoshi Namiki

Department of Anesthesiology, Sapporo Medical University, School of Medicine, South-1, West-16, Chuo-ku, Sapporo, Hokkaido 060-8543, Japan

Key words Zero-heat-flow method · Forehead · Core body temperature

In 1971, Fox and Solman [1] first described the use of an electronic servocontrolled system to achieve almost complete thermal insulation. The temperature measuring probe has two thermistors separated by a thermal insulator, with an electrical heating element mounted at the rear of the probe. The temperatures on the two sides of the insulating layer, as detected by the thermistors, are compared by a differential amplifier. The error signal is used to control the heater current in such a way as to 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 called the "zero-heat-flow" method. As long as a zero-heat-flow condition is maintained, the probe is equivalent to an ideal thermal insulator; i.e., heat loss from the skin surface beneath the probe is prevented and, after a sufficient time, the skin surface temperature will equilibrate with the deep tissue temperature. Monitoring of deep body temperature, especially from the forehead, is now often used in cardiac surgery in Japan. Deep temperature monitoring has also been used in intensive care units [2] and for monitoring of circulatory failure [3]. Although the monitoring of deep body temperature is noninvasive, clinical application of the monitor is limited by the slow initial response time and the slow response time for rapid internal temperature changes. The initial response time of a deep temperature thermometer, extending from the time when the probe is placed on the body surface to the time when the measured temperature become stable, seems to be long. The duration partly depends on the initial temperature of the body surface and the rate of blood flow in the tissue. It takes about 15 min to obtain a final equilibrium temperature within 0.1°C. The response time of the deep body thermometer is still longer than that of conventional catheter thermometers, e.g., a catheter thermometer for measurement of rectal temperature. In patients undergoing cardiac surgery with cardiopulmonary by pass (CPB) [4] or with malignant hyperthermia, in which the body temperature can change very quickly (at a rate of more than 1.0°C per 30 min), deep temperature monitoring does not seem to be as reliable as measurement of the blood temperature from the CPB or jugular vein temperature. Recently, equipment used for deep temperature monitoring has been improved with release of a new instrument (CM-210, Terumo, Tokyo, Japan). Figure 1 shows a cross-sectional schematic view of the probe and a photograph of the new deep temperature monitor. The three main improvements in the monitor are an improvement in operability, a wider range of clinical applications, and improved safety (Table 1). The reliability of the monitor seems to have been improved by the use of initial intensive heating ("quick start") and by a reduction in the diameter of the probe to 43 mm. We evaluated this monitor in comparison with the conventional one.

This study was approved by our hospital's ethical committee on human research, and informed consent was obtained from each patient. Patients with a history of thyroid disease, dysautonomia, Raynaud's syndrome, or malignant hyperthermia were excluded from the study.

Study 1: initial response time

Ten ASA 1 or 2 adult patients who required general anesthesia for surgery on the body surface were enrolled in this study. The mean height was 161 ± 8 cm

Address correspondence to: M. Yamakage
Received: March 12, 2002 / Accepted: July 17, 2002

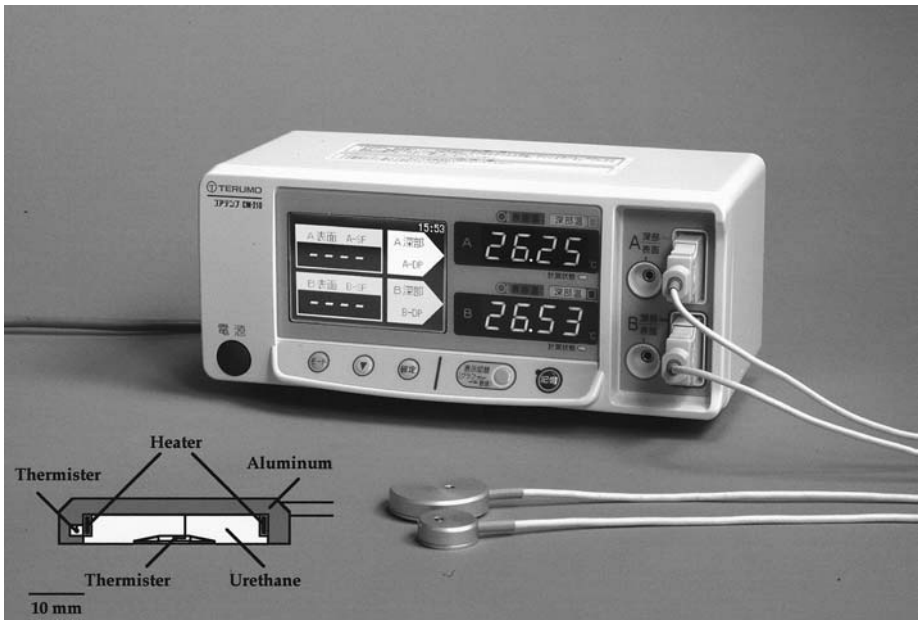

Fig. 1. The newly developed (CM-210) deep body temperature monitoring system with a cross-sectional view of the probe (Terumo, Tokyo, Japan). The main unit of the new system has been reduced in size and can be connected to an external vital monitor. The unit also has a color LCD display that shows the temperatures measured by four probes and can store data (one reading per minute) internally for 2 days

Table 1. Improved features of the newly developed CM-210[a] deep temperature monitoring system

1. Operability
   - Downsized main unit
   - Color LCD displays temperatures measured by all of the probes
   - Connectable to external vital monitor
   - Internal data storage function (1 reading per min for 48 hrs)
2. Measurement of deep body temperature
   - Reduced heat capacity, weight, and thickness of the probes
   - Adoption of initial intensive heating ("quick start")
   - Digital display of temperature in increments of 0.01°C
3. Safety
   - Suitable for EMC standard IEC 60601-2-1, 1993 to reduce electromagnetic noise
   - Lock-type sensor probe connector
   - Increased resistance of cable to alcohol
   - Improvement in detection of deteriorated wires

[a] Terumo, Tokyo, Japan

(±SD), the weight was 61 ± 7 kg, and the age was 47 ± 11 years. The ambient temperature was maintained at 23.5° ± 0.7°C and the ambient relative humidity at 40% ± 8% during the study period. The patients were premedicated with i.m. administration of 0.5 mg of atropine and 2.0–3.0 mg of midazolam 1 h before the operation. An i.v. catheter was inserted into the antecubital vein on the left arm, and acetated Ringer's solution at room temperature (22°–24°C) was infused at approximately 5 ml·kg^{-1}·h^{-1}. Anesthesia was induced by the i.v. administration of 3–5 mg·kg^{-1} of propofol with 0.1 mg·kg^{-1} of vecuronium, and the trachea was intubated. Anesthesia was maintained with 1.0% to 1.5% sevoflurane in nitrous oxide (2 l·min^{-1}) and oxygen (1 l·min^{-1}). Immediately after anesthetic induction, a rectal temperature probe was inserted to a depth of 6 cm and taped in place, and the rectal temperature, which was taken to represent the core temperature, was monitored continuously during the operation by a thermometer (CTM-205, Terumo, Tokyo, Japan). Two probes of conventional (CTM-205) and newly developed (CM-210) core temperature monitors were simultaneously placed on the patient's forehead. The position of the two probes (left or right) was randomized. The measured temperatures were recorded in a personal computer every 10 s. We evaluated the duration from the start of measurement to the stable point. The stable point was defined as the time when the temperature change was <0.1°C·min^{-1}. Data are expressed as mean ± SD, and statistical analysis was performed by the paired *t*-test. $P < 0.05$ was considered significant.

Study 2: response time for rapid internal temperature changes

Ten ASA 2 or 3 adult patients undergoing cardiac surgery with CPB were enrolled in this study. The mean height was 159 ± 8 cm, the weight was 60 ± 6 kg, and the age was 67 ± 9 year. The ambient temperature was maintained at 19.5° ± 3.2°C and the ambient relative humidity at 38% ± 7% during the study period. The patients were premedicated with i.v. administration of 0.4 mg of scopolamine and 2.0–3.0 mg of midazolam 1 h before the operation. An i.v. catheter was inserted, and

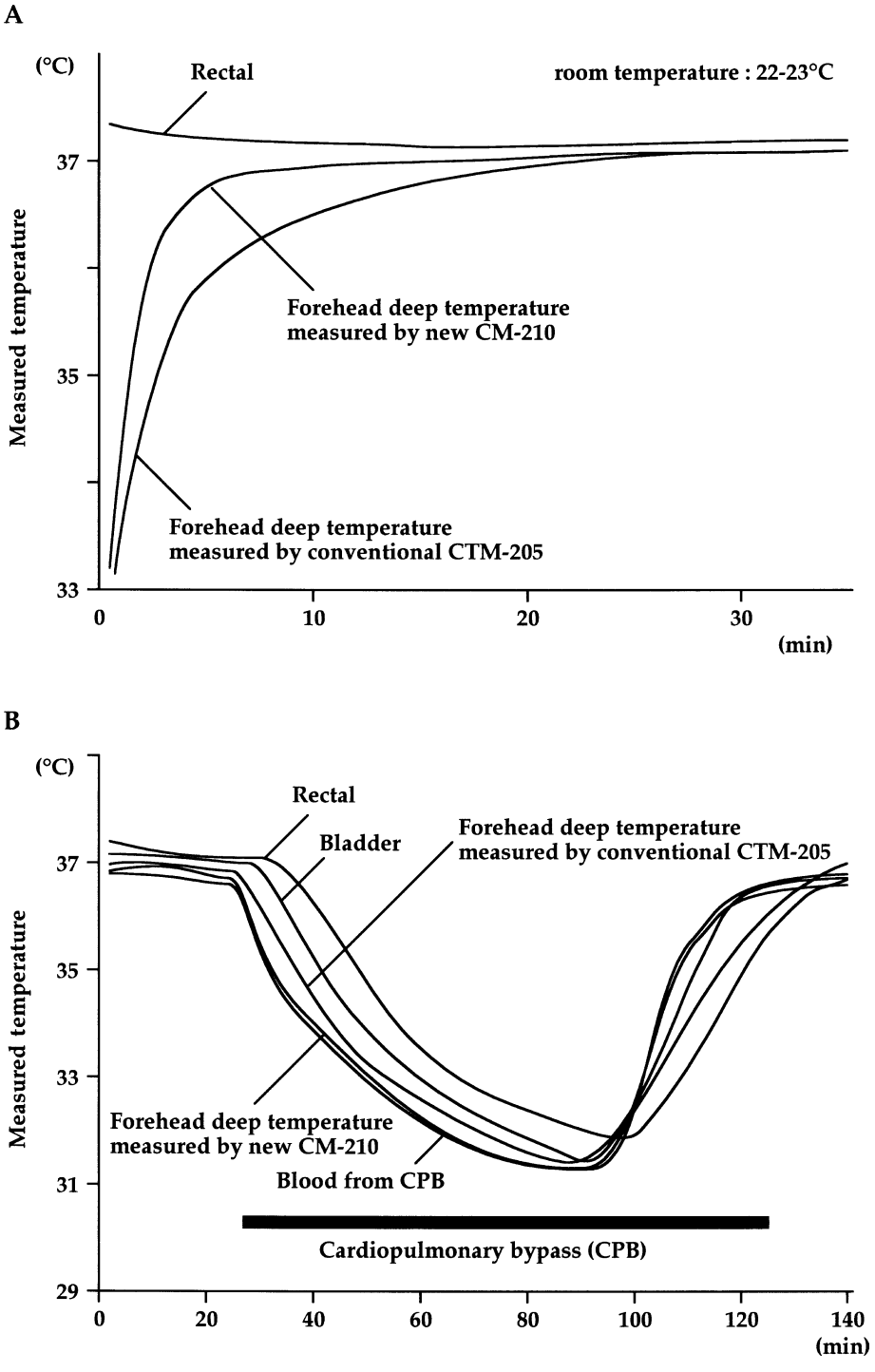

Fig. 2A,B. Results of a study comparating the newly developed deep temperature monitor with a conventional monition. **A** Initial time responses. The initial time response of the new monitor was much shorter than that of the conventional one. **B** Representative data of forehead deep temperature monitoring in cardiac surgery with cardiopulmonary by pass (CPB). The temperature measured by the new system was closer to the blood temperature from the CPB than the bladder temperature or the deep temperature measured by the conventional system

acetated Ringer's solution prewarmed to 37°C was infused at approximately 5 ml·kg^{-1}·h^{-1}. Anesthesia was induced by the i.v. administration of 2–5 mg of midazolam and 0.5–1.0 mg of fentanyl with 0.1 mg·kg^{-1} of vecuronium, and the trachea was intubated. Immediately after anesthetic induction, rectal and bladder temperature probes were inserted, and these temperatures were monitored continuously during the operation by a thermometer (CTM-205). Anesthesia was maintained with continuous infusion of propofol (3–5 mg^{-1}·kg^{-1}·h) and intermittent administration of fentanyl. The anesthetic circuit used in this study was a semiclosed circle system with a total gas flow of 6 l·min^{-1}; the inspiratory gas was neither warmed nor humidified. Two probes of conventional (CTM-205) and newly developed (CM-210) core temperature monitors were simultaneously placed on the patient's forehead. The position of the two probes (left or right) was randomized. The

measured temperatures were recorded in a personal computer every 10 s. Measurements of deep body temperature and bladder temperature were analyzed by calculating the correlation with the blood temperature from the CPB. Statistical analysis was performed using correlation analysis, and data are expressed as r (correlation coefficient) values.

As shown in Fig. 2, the initial time response was much shorter [5.6 ± 1.2 min (mean $\pm$ SD) $<0.1°C \cdot min^{-1}$] than that with the use of conventional equipment (16.5 ± 4.2 min), and the measured temperature was closer to the blood temperature from the CPB ($r = 0.92$) than was either the bladder temperature ($r = 0.81$) or the conventionally measured deep temperature ($r = 0.85$).

Although noninvasive deep body temperature monitoring seems to be used at present only in the field of cardiac surgery because of its high cost and relatively slow response, it is expected that advanced deep temperature monitoring that has a quick response will be used in other kinds of surgery and anesthesia in the future.

References

1. Fox RH, Solman AJ (1971) A new technique for monitoring the deep body temperature in man from the intact skin surface. J Physiol 212:8–10
2. Togawa T, Nemoto T, Tsuji T, Suma K (1979) Deep temperature monitoring in intensive care. Resuscitation 7:53–57
3. Tsuji T (1987) Patient monitoring during and after open heart surgery by an improved deep body thermometer. Med Prog Tech 12:25–38
4. Yamakage M, Kawana S, Watanabe H, Namiki A (1993) The utility of tracheal temperature monitoring. Anesth Analg 76:795–799