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Accuracy and precision of a novel non-invasive core thermometer

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Background. Accurate measurement of core temperature is a standard component of perioperative and intensive care patient management. However, core temperature measurements are difficult to obtain in awake patients. A new non-invasive thermometer has been developed, combining two sensors separated by a known thermal resistance ('double-sensor' thermometer). We thus evaluated the accuracy of the double-sensor thermometer compared with a distal oesophageal thermometer to determine if the double-sensor thermometer is a suitable substitute.

Methods. In perioperative and intensive care patient populations (n=68 total), double-sensor measurements were compared with measurements from a distal oesophageal thermometer using Bland–Altman analysis and Lin's concordance correlation coefficient (CCC).

Results. Overall, 1287 measurement pairs were obtained at 5 min intervals. Ninety-eight per cent of all double-sensor values were within $\pm 0.5°C$ of oesophageal temperature. The mean bias between the methods was $-0.08°C$; the limits of agreement were $-0.66°C$ to $0.50°C$. Sensitivity and specificity for detection of fever were 0.86 and 0.97, respectively. Sensitivity and specificity for detection of hypothermia were 0.77 and 0.93, respectively. Lin's CCC was 0.93.

Conclusions. The new double-sensor thermometer is sufficiently accurate to be considered an alternative to distal oesophageal core temperature measurement, and may be particularly useful in patients undergoing regional anaesthesia.

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Perioperative body temperature monitoring has become routine because the deleterious effects of accidental core hypothermia are well established,[1–3] as are complications associated with core hyperthermia.[4–6] It is easy to obtain accurate core temperature measurements from several locations of the human body with relatively invasive methods. Three standard core temperature measurement sites are the pulmonary artery, nasopharynx, and the distal oesophagus. None of these sites is easy to use in sedated critical care patients or patients having regional anaesthesia.[7] Yet adequate core temperature monitoring is clearly indicated in these populations and recommended by the National Institutes for Health and Clinical Excellence's (NICE) Guideline for the management of inadvertent perioperative hypothermia.[8] Patients having neuraxial anaesthesia are as likely to become hypothermic as patients with general anaesthesia,[9–11] and there is no reason to believe that they are any less likely to suffer hypothermia-related complications. Detecting hyperthermia is also important in both populations.

Several non-invasive temperature measurements are currently used to estimate core temperature. These methods include temperature measurements in the mouth,[12] the axilla,[13–16] the skin surface,[17] aural canal,[18] or temporal artery.[19 20] None has proven consistently accurate enough for routine perioperative or critical care use or is suitable for continuous temperature monitoring. Recently, a new type of continuous, non-invasive thermometer has been developed, consisting of two thermometers separated by a known thermal resistance ('double sensor', Fig. 1). The sensor consists of two temperature probes on each side of a standardized insulator (one side adjacent to the patient's

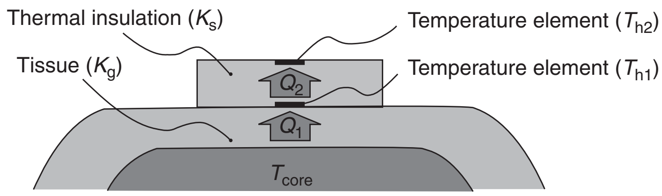

Fig 1 Two temperatures are measured: T_{h1} for skin temperature and T_{h2} for 'environment-side' temperature. The heat coefficient of the insulating material (K_s) is known. An additional parameter that has to be taken in account is the estimated heat transfer coefficient of human tissue (K_g). A formula for calculating core temperature with an empiric human tissue heat transfer coefficient using the double-sensor is thus: $T_{core} = T_{h1} + (K_s/K_g)(T_{h1} - T_{h2})$.

skin and the other facing the environment) in a plastic shell which can be affixed to a patient's forehead. The new thermometer has already been tested in firefighters in a simulated work environment to determine heat strain and provided adequately accurate measurements.[21]

We compared the new non-invasive double-sensor thermometer in a perioperative and intensive care patient population with an established invasive core temperature measurement method (distal oesophageal temperature) to determine the accuracy and sensitivity/specificity of the new method for the detection of hypothermia and fever. We hypothesized that the new double-sensor thermometer was an adequate clinical substitute for the invasive distal oesophageal thermometer. For reference, we also evaluated the accuracy of a simple forehead skin temperature, adjusted upwards by 2°C.

Methods

Our study was approved by the Ethics Committee of the Medical University of Vienna and written informed consent was obtained from all participants. All patients were 18–80 yr old and were studied perioperatively (36 patients) during non-cardiac or non-neurosurgical surgery or in general intensive care units (ICU, 32 patients). All patients were anaesthetized and undergoing mechanical ventilation. Patients studied during surgery were not restudied, if admitted to an ICU. Patients were excluded, if attachment of the double-sensor to the forehead via the headband was not possible due to surgical incision, injury, or small head circumference. Patients were also excluded, if the oesophageal sensor could not be properly positioned because of surgery or coexisting disease.

Protocol

Thermal management in the operating theatre was standardized and comprised forced-air warming (Bair Hugger, Arizant, MN, USA). Depending on the location of surgery, an upper- or lower-body forced-air blanket was used (model #522 or model #525) with a model #750 warming unit. The plastic flap of the upper body cover was positioned to cover the face and neck, but left the double sensor exposed to the ambient environment. ICU patients were warmed with a whole-body forced-air cover (model #300) if hypothermic (<36°C) or cooled with forced air (Polar Air, Arizant, MN, USA). The double sensor was not specifically shielded against warm or cold air.

Measurements

Patient characteristics were recorded. Anaesthetic management was at the discretion of the attending anaesthetist. Double-sensor thermometer measurements were conducted by an experienced researcher who was trained to use the device. The reusable sensor was held adjacent to the patients' foreheads with an elastic headband, and a small amount of contact gel was applied between sensor and skin. At least 10 min was allowed for thermal equilibration, after the sensor was applied.

Calculation of core temperature

Core temperature (T_{core}) is estimated from the double-sensor system from T_{h1} (skin temperature under the insulator), T_{h2} (temperature above the insulator), the heat conduction coefficient (K_s) of the insulator (calibrated at Draeger AG for each double sensor), and an empirically estimated heat transfer coefficient of human tissue (K_g=45 W m^{-2} K^{-1}). The formula for calculating core temperature with the empiric human tissue heat transfer coefficient using the double sensor is thus:

$$T_{core} = T_{h1} + \frac{K_s}{K_g}(T_{h1} - T_{h2}).$$

Forehead skin temperature was also recorded from T_{h1}. As in previous studies,[22 23] a 2°C offset was added to approximate core temperature to account for skin temperature being less than core temperature. We included the analysis of the forehead temperature +2°C in the present study primarily to show that the double-sensor thermometer markedly outperforms a simple forehead thermometer with a fixed correction like, for example, a liquid crystal thermometer. A distal-oesophageal, single-use thermometer (Smiths Medical, London, UK) was introduced under direct laryngoscopic vision and was used as the reference core temperature. Oesophageal temperature is considered one of the four reliable core temperature monitoring sites, the others being pulmonary artery, tympanic membrane (measured with a thermocouple), and nasopharynx.[24]