British Journal of Anaesthesia **111** (5): 768–75 (2013)
Advance Access publication 25 June 2013 · doi:10.1093/bja/aet217

BJA

Temporal and spatial dispersion of human body temperature during deep hypothermia

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Editor's key points

- There is uncertainty as to the best site to measure the core body temperature from.
- Spatial and temporal relationship of temperature measurements were investigated in patients undergoing cardiothoracic surgery.
- The sensors should be placed as close as possible to the site of interest to be measured.
- A non-linear relationship between sensor sites was found; contributory factors need further study.

Background. Clinical temperature management remains challenging. Choosing the right sensor location to determine the core body temperature is a particular matter of academic and clinical debate. This study aimed to investigate the relationship of measured temperatures at different sites during surgery in deep hypothermic patients.

Methods. In this prospective single-centre study, we studied 24 patients undergoing cardiothoracic surgery: 12 in normothermia, 3 in mild, and 9 in deep hypothermia. Temperature recordings of a non-invasive heat flux sensor at the forehead were compared with the arterial outlet temperature of a heart–lung machine, with the temperature on a conventional vesical bladder thermistor and, for patients undergoing deep hypothermia, with oesophageal temperature.

Results. Using a linear model for sensor comparison, the arterial outlet sensor showed a difference among the other sensor positions between −0.54 and −1.12°C. The 95% confidence interval ranged between 7.06 and 8.82°C for the upper limit and −8.14 and −10.62°C for the lower limit. Because of the hysteretic shape, the curves were divided into phases and fitted into a non-linear model according to time and placement of the sensors. During cooling and warming phases, a quadratic relationship could be observed among arterial, oesophageal, vesical, and cranial temperature recordings, with coefficients of determination ranging between 0.95 and 0.98 (standard errors of the estimate 0.69–1.12°C).

Conclusion. We suggest that measured surrogate temperatures as indices of the cerebral temperature (e.g. vesical bladder temperature) should be interpreted with respect to the temporal and spatial dispersion during cooling and rewarming phases.

Keywords: body temperature; deep hypothermics circulatory arrest; intraoperative monitoring; mathematical model; non-linear model

Accepted for publication: 18 March 2013

Suitable sensors and sensor placement for the correct measurement of core body temperature (CBT) have been the subject of continuous debate since the first published measurements of human body temperature by Carl Reinhold August Wunderlich.[1] Thermodynamic monitoring has shown that the slopes of warming and cooling differ according to sensor location and tissue type. Thus, estimating the brain temperature or CBT, respectively, by monitoring peripheral surrogates implies knowledge about the dynamic aspects of temperature changes. To demonstrate the wide range of human body temperatures, iatrogenic hypothermia can be used as a model, as it is reversible and of considerable clinical interest as opposed to accidental hypothermia, which may result in shivering and lead to severe cardiocirculatory or coagulative complications, and tissue damage.[2 3]

By lowering temperature below the optimal temperature for intracellular enzymatic systems, hypothermia has been in therapeutic use for decades to appreciably slow down cell metabolism.[4] Mild hypothermia (34–37°C) has been reported to ameliorate the neurological outcome after cardiopulmonary resuscitation.[5–8] Additionally, the metabolic advantages of deep hypothermia (<30°C) have been used during operations on great vessels, which require a circulatory arrest of several minutes to clear the surgical field. Thus, for accidental and also for the therapeutic use of hypothermia, an easy-to-use, reliable, and secure system for monitoring the brain temperature or CBT would be needed. However, previous reports show remarkable disparity regarding proper sensor placement and temporal interdependency.[9–12]

The current study evaluates temporal and spatial dispersion of human body core temperature in induced hypothermia, using four sites of temperature measurement. A novel cranial heat flux sensor has shown to be a reliable measure of body

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core temperatures of patients in intensive care under normothermic conditions.[13] It displayed good applicability for the determination of heat strain during exercise and has been tested under extreme environmental conditions.[14] The other sites were the arterial outlet of the heart–lung machine, the vesical bladder, and the oesophagus.

Thus, by correlating temperatures in normothermia, mild and deep hypothermia obtained at different sites of the human body, we aim to integrate these into a projection regarding their inter-relationship and to discuss its implications for clinical medicine.

Methods

Patients

The following study was performed at the German Heart Institute Berlin (DHZB). All patients included in the study were recruited within 1.5 yr. All participants gave their written informed consent.

We enrolled 12 patients who underwent surgery in normothermia and 12 patients who underwent surgery under hypothermic conditions (3 in moderate hypothermia and 9 in deep hypothermia). The study was designed according to the ethical statutes of the Declaration of Helsinki, Revision 6, 2008. It was approved by the Ethics Committee of the Charité – Universitätsmedizin Berlin.

All patients suffered from severe cardiac diseases or abnormalities that provided an indication for surgical reconstruction (American Society of Anesthesiologists Classification, ASA IV) and received open-heart surgery. Exclusion criteria were met if a proper fixation of the cranial double sensor the Doppler/pulse oximetry unit or both was not possible. In five of the nine deep hypothermic patients, a temporary circulatory arrest (DHCA) was needed. Body temperatures were measured at the head using a heat flux sensor, oesophageal (only in deep hypothermic patients), at the arterial outlet of the membrane oxygenator, and in the vesical bladder.

Because of the fact that surgery in deep hypothermia (i.e. aortic arch aneurysm) often takes place under emergency conditions, we also studied cases of moderate hypothermia. For simplification, patients were therefore allocated to three groups depending on the extent of hypothermia (normothermia, moderate hypothermia, and deep hypothermia). To focus on the different phases of deep hypothermia, the course of each measurement was divided into five phases, namely P1–P5, representing specific periods of the cooling and rewarming processes.

Experimental set-up and protocol

Data were acquired during four types of surgery: aortic arch surgery (9), heart valve replacement (13), tumour extirpation (1), and pulmonary thrombectomy (1). Operations on the aortic arch frequently require temporary circulatory arrest in deep hypothermia. Thus, they provide the opportunity to record core temperatures as low as 9.3 and 13.8°C (depending on the sensor position). We chose to study heart valve replacements of the aortic, the tricuspid, the mitral, or a combination of valves, because they are routine procedures on the open heart with high comparability. They were performed in normothermic patients using a cardiopulmonary bypass (CPB). Operations such as tumour extirpation or the placement of a left ventricular assist device were also performed predominantly under normothermic conditions.

Transoesophageal echocardiography (TOE) was used intermittently during surgery in deep hypothermia and continuously during valve replacement surgery in mild hypothermia and normothermia.

The temperature sensors were applied after the patients had been brought into the operating theatre (OT) and were positioned on the operating table. Sensors were removed after the surgeons had finished the sutures, but before the patients left the OT.

Thermal management in the OT was performed according to a standardized clinical protocol. Patients were cooled and warmed using CPB. Ice packs were used on the head as an additional means of neuroprotection. The sensors were kept at a secure distance from the ice to ensure data accuracy. Sodium nitroprusside was administered by the anaesthesiologist to ensure peripheral vasodilation of the arterial and venous vascular bed and to provide a homogeneous change of the body temperature.

The type of anaesthesia, other medications given, and the mode of mechanical ventilation followed a standardized clinical protocol, in accordance with the guidelines of the Society of Cardiovascular Anesthesiologists (http://www.scahq.org/ClinicalPracticeGuidelines/guideLines.html) and the European Society of Cardiology (http://www.escardio.org/guidelines-surveys/esc-guidelines/Pages/GuidelinesList.aspx).

Three agents were used for induction: (i) etomidate at a dose of 0.3–0.4 mg kg^{-1}, (ii) pancuronium bromide at a dose of 0.05–0.1 mg kg^{-1}, (iii) and sufentanil at a dose of 0.5–1 $\mu g\ kg^{-1}$. For maintenance during surgery, propofol was administered at a dose of 3–6 mg $kg^{-1}\ h^{-1}$ according to bispectral index combined with sevoflurane at an end-tidal concentration of 0.5–1.0 vol.%. For analgesia, sufentanil was administered at a dose of 0.3–0.8 $\mu g\ kg^{-1} h^{-1}$. The sevoflurane administration was stopped after the patients had been connected to CPB. Sodium nitroprusside was administered at a dose of 0.5–8 $\mu g\ kg^{-1}\ min^{-1}$.

During surgery, the following parameters were recorded: arterial pressure (invasive arterial measurement), heart rate, electrocardiogram, pulse oximetry, blood gas analysis, and blood flow. Additionally, CBT (measured by the double sensor on the forehead), capillary-venous oxygen saturation, blood flow in microcirculation, and relative amount of haemoglobin (measured by laser-doppler and tissue-spectrometry at forehead and tibia by Oxygen 2 See [O2C], LEA Medizintechnik, Giessen, Germany).

Anaesthesia and CPB

In order to provide an acceptable operational field, the movement of the heart and the lungs sometimes has to be stopped. Via insertions in the right atrium and the ascending aorta, all