

## Changes in core temperature compartment size on induction of general anaesthesia

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### Summary

A two-compartment model of temperature distribution estimates the core compartment to occupy 66% of body mass at rest, while the peripheral compartment comprises the remainder. General anaesthesia impairs thermoregulation by central and peripheral actions. Peripheral vasodilatation accelerates heat transfer from the core to peripheral compartment causing the core compartment to cool and expand in size. Core hypothermia may be a significant cause of postoperative morbidity. This undocumented change in the size of the core compartment on induction of anaesthesia can be calculated. Core size increased from the established value of 66% before induction of general anaesthesia to 71.2 (sd 6)% of body mass, 20 min after induction of anaesthesia ( $P=0.0001$ ). On induction of general anaesthesia, the core compartment cools and expands while the peripheral compartment warms and contracts by a corresponding amount. Measurement of the magnitude of changes in core:periphery heat distribution on induction of anaesthesia contribute to a clearer understanding of the pathophysiology of perioperative hypothermia. (*Br. J. Anaesth.* 1998; 81: 861–864).

Keywords: temperature, core; temperature, periphery; anaesthesia, general

Normal physiological function requires intact thermoregulatory mechanisms. General anaesthesia impairs thermoregulation by central and peripheral actions. The resultant perioperative hypothermia occurs in three distinct stages.<sup>1</sup> This study examines the initial stage in which peripheral vasodilatation accelerates heat transfer from the core to peripheral compartment. This heat redistribution causes the core compartment to cool and expand with minimal change in overall total body heat content. This unquantified expansion of core size may contribute to the second stage of anaesthesia-induced hypothermia as the core compartment expands towards the body surface and accelerates heat loss. The resulting mild to moderate hypothermia is likely to increase perioperative morbidity by causing increased myocardial workload, impaired oxygen delivery and impaired coagulation. Calculation of both the magnitude and rate of change in core size may further elucidate the pathophysiology of perioperative hypothermia and enable the development of techniques to improve

the efficiency of active postoperative rewarming. Core size after induction of anaesthesia was therefore measured to determine the magnitude and rate of these changes.

### Patients and methods

The study was approved by Southampton Joint Ethics Committee, and all patients gave written informed consent. Six adult elective surgical patients were studied before and after induction of general anaesthesia. The general anaesthetic technique and patient characteristics were matched as closely as possible to the technique used during the calculation of total heat content after induction of general anaesthesia.<sup>2</sup> No premedication was given. Anaesthesia was induced with propofol 3 mg kg<sup>-1</sup> i.v., fentanyl 2–3 µg kg<sup>-1</sup> i.v. and vecuronium 0.1 mg kg<sup>-1</sup> i.v. The trachea was intubated and the lungs ventilated with a Penlon 200 ventilator using oxygen:nitrous oxide ( $F_{I_{O_2}} \geq 0.40$ ) to maintain normocapnia ( $P_{a_{CO_2}}$  3.5–4.5 kPa). A heat and moisture exchanging filter (Mallinckrodt Medical Hygrobac “S”) was placed on the catheter mount. Anaesthesia was maintained using 0.5–0.75% end-tidal isoflurane. Patients were covered with a light wool blanket before induction of anaesthesia and during temperature recordings. Room temperature was maintained at 22°C.

Core temperature ( $T_c$ ) was measured with a tympanic membrane thermocouple probe (Mallinckrodt, Northampton, UK) placed before induction of anaesthesia after confirmation that the external auditory meatus was free from wax. Mean peripheral temperature ( $T_p$ ) was recorded with four calibrated thermistors (Yellow Springs 400) placed on the upper arm, lateral chest wall, lateral thigh and lateral calf ( $T_p = 0.3$  (chest wall + upper arm) + 0.2 (leg + thigh)).<sup>3</sup> Temperature data were recorded to a temperature logger<sup>4</sup> at 1-min intervals for 5 min before and 20 min after induction of general anaesthesia.

### CALCULATION OF CORE COMPARTMENT SIZE

Calculation of core compartment size makes several assumptions which are considered in detail in the discussion: (1) a two-compartment (core and periphery) model of heat distribution; (2) core mass under thermoneutral conditions represents 66% total body mass<sup>5</sup>; (3) specific heat capacity is identical for core

and peripheral compartments<sup>6</sup>; and (4) after induction of general anaesthesia, net body heat content decreases at  $0.026 \text{ kJ}^{-1} \text{ kg}^{-1} \text{ min}^{-1}$ .<sup>2</sup>

The derivation of the core compartment size is detailed in the appendix.

#### STATISTICAL ANALYSIS

Results are given as mean (SD). Changes in core and peripheral temperature were analysed by analysis of variance (ANOVA). Significance was taken as  $P < 0.05$ .

## Results

The mean age of the patients was 53.7 (range 32–74) yr, mean weight was 65.2 (SD 8.9) kg and mean body mass index was 22.1. The anaesthetic room temperature was maintained at  $22.1 \pm 0.3^\circ\text{C}$  with humidity of  $39.7 \pm 3.2\%$ .

After induction of anaesthesia, core temperature decreased by  $0.63$  ( $0.32$ ) $^\circ\text{C}$  from  $37.0$  ( $0.27$ ) $^\circ\text{C}$  to  $36.4$  ( $0.45$ ) $^\circ\text{C}$  over a 20-min period ( $P = 0.0001$ ). Over the same period, mean peripheral temperature increased by  $0.32$  ( $0.22$ ) $^\circ\text{C}$  from  $33.0$  ( $0.74$ ) $^\circ\text{C}$  to  $33.28$  ( $0.70$ ) $^\circ\text{C}$  ( $P < 0.01$ ) (fig. 1). Core size increased from the established value of 66% before induction of general anaesthesia to 71.2 (6)% of body mass, 20 min after induction of anaesthesia ( $P < 0.01$ ) (fig. 2).

## Discussion

These results show that over a 20-min period after induction of general anaesthesia, core temperature compartment size increased from 66% to 71% of total body mass, while the peripheral compartment decreased from 34% to 29%. After induction of general anaesthesia, the core compartment cools and expands while the peripheral compartment warms and contracts. This is the first study to document the magnitude of these changes.

Under normal physiological conditions, thermal energy is transferred from the core to the periphery down a temperature gradient. Most thermal energy is transferred by blood flow from core to peripheral tissues. Anaesthetic-induced inhibition of thermo-

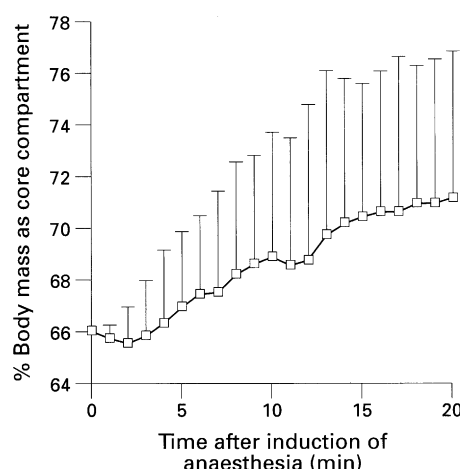


Figure 2 Changes in percentage core size after induction of general anaesthesia.  $P = 0.0001$ . Error bars represent 1 SD.

regulatory vasoconstriction increases peripheral blood flow and accelerates heat transfer from the core to the periphery.<sup>1</sup> The subsequent decrease in core temperature and increase in peripheral temperature is well documented.<sup>2,7,8</sup> Redistribution of heat accounts for 87% of the decrease in core temperature that occurs over the initial 30 min after induction of general anaesthesia, the remainder being caused by the 20% reduction in metabolic heat production and increased heat loss.<sup>9</sup>

Changes in core and peripheral size occur only in approximately the first 30 min after induction of general anaesthesia after which time heat loss exceeds heat production and both core and peripheral compartments cool further.<sup>1</sup> As the peripheral compartment cools, thermoregulatory vasoconstriction decreases peripheral heat loss and acts to sequester heat within the core compartment.<sup>1</sup> Under these conditions it has been proposed that the core compartment retracts to a size smaller than normal (i.e. less than 66% of total body mass)<sup>1</sup> but no calculations have been made to support this theory. Changes in core size have previously been calculated only in hot environments ( $45^\circ\text{C}$ ) where total body heat content increases and core size expands to 79% of total body mass.<sup>5</sup>

The results of this study were calculated based on several assumptions. One anatomical site is used to represent mean core temperature. It is a method used regularly in thermoregulatory studies. Tympanic membrane temperature correlates well with cerebral, oesophageal, nasopharyngeal and pulmonary artery catheter temperature and is regarded as the "gold standard" for core temperature measurements by many authors.<sup>10</sup> Variation in temperature between these sites is less than  $0.5^\circ\text{C}$  under normothermic conditions. Changes in core temperature are rapidly detected at the tympanic membrane and is therefore considered an appropriate site to represent core temperature in this study.

Peripheral temperature is more variable between sites because it is the site of thermoregulatory vasoconstriction. Within the tissue itself, small temperature variations occur between septa dividing fatty layers and different tissues<sup>11</sup> but temperature of tissues regarded as "peripheral" usually varies by no more than  $5^\circ\text{C}$  except in the presence of moderate to

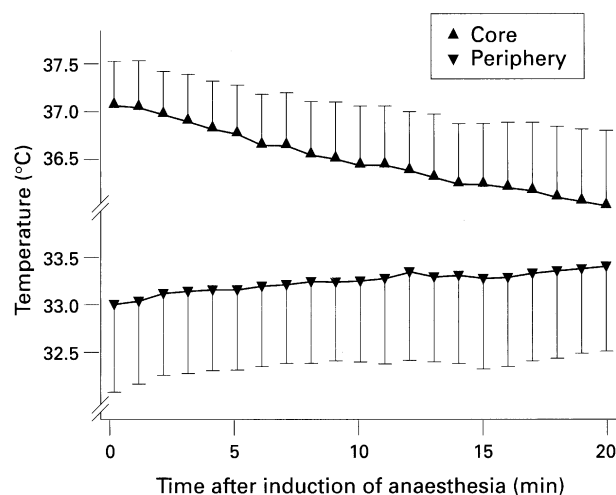


Figure 1 Changes in core and mean peripheral temperatures after induction of general anaesthesia.  $P = 0.0001$  for both sites. Error bars represent 1 SD.

severe hypothermia where peripheral vasoconstriction of fingers and toes can be severe. Skin covering the limbs is the coldest of peripheral sites under most conditions, whereas that covering the trunk is warmer.<sup>12</sup> A weighted average is used to calculate a mean value and has been shown to be a reasonable approximation to the true value.<sup>13</sup>

Two-compartment modelling of temperature distribution is a concept established in early studies of thermoregulation<sup>11 14 15</sup> and is used widely for modelling perioperative thermal changes. The transition from core to peripheral compartment occurs at varying depths at different anatomical sites. Core temperature extends to within 2.5–7 mm from the skin over tissues of the upper arm and thigh.<sup>11 15</sup> In more peripheral tissue, core temperature may not extend so close to the surface. A recent study established that while tissues 18 mm deep to the sole of the foot correlated well with core temperature ( $r^2=0.87$ ), a poorer correlation was shown with tissue at 8 mm depth ( $r^2=0.75$ ).<sup>16</sup> Rectal and vaginal temperature have been documented as not reaching maximum values until a depth of 5 cm in each cavity was reached.<sup>15</sup> However, rectal temperature is recognized as being slightly higher than true core temperature through the effects of thermogenic bacteria and thus this depth may be only an approximation. Thus core temperature appears to extend to within a few centimetres of all body surfaces where it decreases by approximately 5°C across the peripheral compartment. The apparent extension of the core compartment to within a few centimetres of the body surface and the sharp decrease in temperature close to the body surface allows approximation to a two-compartment model. The two-compartment model allows calculation of core and peripheral heat distribution at rest,<sup>5</sup> after induction of general anaesthesia<sup>2</sup> and during hyperthermia.<sup>5</sup> It has also been used to investigate the effect of morphometric characteristics on perioperative hypothermia<sup>7 17</sup> and is central to an understanding of the mechanisms causing post-operative hypothermia in patients after hypothermic cardiopulmonary bypass.<sup>18 19</sup>

Calculation of energy content of tissues assumes that tissues of core and peripheral compartments have similar specific heat capacity (SHC). SHC of tissue (heart, liver, kidney, brain, spleen, blood) contained within the core compartment varies from 3.60 to 3.89 kJ kg<sup>-1</sup> K<sup>-1</sup>. Although there are no specific studies, bone can be regarded as mostly at core temperature but has a significantly lower SHC of 1.30 kJ kg<sup>-1</sup> K<sup>-1</sup>. Tissues of the peripheral compartment are mostly skin, subcutaneous fat and some muscle. SHC of skin is 3.47 kJ kg<sup>-1</sup> K<sup>-1</sup>, fat 2.30 kJ kg<sup>-1</sup> K<sup>-1</sup> and muscle 3.72 kJ kg<sup>-1</sup> K<sup>-1</sup>.<sup>6 20 21</sup> Difficulties exist in determining the amount of tissues such as fat, bone and muscle that should be allocated to each compartment. In addition, changes in core size with hypothermia change the proportions of tissue within each compartment. Thus determination of mean SHC of core and peripheral compartments involves several unknown variables. No estimates have been made of mean values for core and peripheral compartments but it is thought that use of a mean value for both compartments is an adequate approximation for the calculation of thermal energy content.<sup>22</sup>

The change in body heat content after induction of

general anaesthesia is small. In six separate studies, estimates of net heat loss during anaesthesia have varied between 42 and 130 kJ h<sup>-1</sup>.<sup>9 13</sup> This variability appears to be caused by different anaesthetic techniques and differences in room temperature at which the studies were carried out. Different anaesthetic techniques may vary both in their effects on the internal redistribution of body heat and the ensuing rate of heat loss. The results of this study are specific both to the anaesthetic technique and room temperature, but because changes in heat content as a proportion of total body heat are small, it is likely that core size will change by similar magnitude when using other anaesthetic agents.

Heat loss on induction of anaesthesia calculated by Matsukawa and colleagues used the most accurate methodology of any study.<sup>2</sup> Six minimally clothed volunteers were anaesthetized and studied for 3 h at a room temperature of 22°C during which overall heat balance was determined from the difference between cutaneous heat loss (thermal flux transducers) and metabolic heat production (oxygen consumption). Arm and leg tissue heat content was determined by the use of 19 i.m. thermocouples, 10 skin temperatures and "deep" foot temperature. Data from this work were therefore used for this study to calculate total body heat at any given time after induction of general anaesthesia. Caution must be exercised when applying data from one study to another, but anaesthetic technique and environmental conditions were matched closely in the study population and the subsequent changes in core and peripheral temperatures were of similar magnitude in both studies. There was a difference in body mass index (BMI) which was higher in the study by Matsukawa and colleagues (25.6 *vs* 22.1). Although body fat has been regarded as an insulating layer, the effect of body fat on heat loss is variable and some studies have shown no effect on heat loss during anaesthesia.<sup>7</sup> Increased body fat content reduces the amount of redistribution hypothermia during the first hour of anaesthesia but the effects are most marked at extremes of body fat content.<sup>17</sup> The small differences in BMI and subsequent differences in heat loss between the two groups is small and the effects on calculation of core size are therefore minimal.

This study was limited to a 20-min period after which patients were moved to the operating theatre and surgery began. At this stage, many variables make further calculations of body heat content inaccurate through immeasurable heat loss from removal of insulating blankets,<sup>23</sup> application of cold surgical cleaning fluid, cooling by convection from theatre ventilation, evaporative water loss from open body cavities and loss of heat in body fluids.<sup>1</sup> The rate of heat loss documented by Matsukawa and colleagues<sup>2</sup> and used for these core size calculations was measured in subjects in a stable environment and therefore cannot be applied when the patient is moved to the operating theatre where heat loss during surgery is approximately twice that documented in the stable environment of the anaesthetic room.<sup>23</sup>

Initial redistribution hypothermia is followed by a distinct second stage in which heat loss exceeds metabolic heat production to cause a slow decrease in core temperature. The increased heat loss during this second stage may be contributed to by the expansion of core compartment towards the body

surface resulting in a greater rate of heat loss across the shallower peripheral compartment. This study has documented for the first time changes in heat distribution in the first of three stages of anaesthetic-induced hypothermia. It is hoped that the results will be a useful measure in the study of the pathophysiology of hypothermia under anaesthesia.

## Appendix

Total body heat content in a resting state, before induction of general anaesthesia can be calculated from the equations:

Mean body temperature ( $T_b$ )<sup>5</sup>

$$T_b = 0.66 T_c + 0.34 \quad (1)$$

Total body heat content ( $Q_b$ )<sup>5</sup>

$$Q_b = M_b \cdot s \cdot T_b \quad (2)$$

where  $s$  = mean specific heat capacity of human tissue ( $3.475 \text{ kJ kg}^{-1} \text{ K}^{-1}$ );  $Q_b$  = total body heat content;  $Q_c$  = total core heat content;  $Q_p$  = total peripheral heat content;  $T_b$  = mean body temperature;  $T_c$  = mean core (tympanic membrane) temperature;  $T_p$  = mean peripheral temperature;  $M_b$  = total patient mass;  $M_c$  = core mass; and  $M_p$  = peripheral mass.

After induction of general anaesthesia, total body heat content decreases linearly at  $0.026 \text{ kJ}^{-1} \text{ kg}^{-1} \text{ min}^{-1}$  ( $130 \text{ kJ h}^{-1}$ ).<sup>2</sup> Using the same anaesthetic technique, total body heat content at time " $t$ " after induction of anaesthesia can be calculated from the equation:

$$Q_{b_i} (\text{kJ}) = Q_{b_0} - (0.026 \cdot M_b \cdot t)$$

where  $Q_{b_0}$  = total body heat content before induction of anaesthesia; and  $Q_{b_i}$  = total body heat content at time " $t$ ".

Calculation of core ( $x$ ) compartment size at time " $t$ " can be made by re-arranging the equation:

$$Q_{b_i} = (s \cdot T_c \cdot M_b \cdot x) + (s \cdot T_p \cdot M_b \cdot (1 - x))$$

where  $x$  = core size;  $T_c$  = mean core temperature at time " $t$ ";  $T_p$  = mean peripheral temperature at time " $t$ ".

Calculations for the derivation of " $x$ " are outlined below.

$$Q_b = Q_c + Q_p \quad (3)$$

$$Q_b = (T_c \cdot s \cdot M_c) + (T_p \cdot s \cdot M_p) \quad (4)$$

But  $M_p = M_b - M_c$  and therefore, combining equations (2) and (4):

$$Q_b = (T_c \cdot s \cdot M_c) + (T_p \cdot s \cdot M_b) - (T_p \cdot s \cdot M_c) \quad (5)$$

Rearranging equation (5):

$$Q_b - (T_p \cdot s \cdot M_b) = (M_c \cdot s) (T_c - T_p) \quad (6)$$

$$M_c = \frac{Q_b - (T_p \cdot s \cdot M_b)}{s \cdot (T_c - T_p)} \quad (7)$$

After induction of general anaesthesia, body heat content decreases at  $0.026 \text{ kJ}^{-1} \text{ kg}^{-1} \text{ min}^{-1}$ . Thus at a time " $t$ ":

$$Q_{b_i} = Q_{b_0} - (0.026 \cdot M_b \cdot t) \quad (8)$$

Therefore, from equation (7):

$$M_{c_i} = \frac{Q_b - (0.026 M_b \cdot t) - (T_p \cdot s \cdot M_b)}{s (T_c - T_p)} \quad (9)$$

$Q_{b_0} = M_b \cdot s \cdot T_{b_0}$  from equation (2)

Substitute

$$M_{c_i} = \frac{(M_b \cdot s \cdot T_{b_0}) - (0.026 M_b \cdot t) - (T_p \cdot s \cdot M_b)}{s (T_c - T_p)} \quad (10)$$

$$M_{c_i} = \frac{M_b (s (T_{b_0} - T_p) - 0.026 t)}{s (T_c - T_p)} \quad (11)$$

$$\frac{M_{c_i}}{M_b} = \frac{s (T_{b_0} - T_p) - 0.026 t}{T_c - T_p} \quad (12)$$

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