Accuracy and precision of “deep sternal” and tracheal temperatures at high- and low-fresh-gas flows

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Summary

The accuracy of tracheal temperature as a measure of core temperature is relatively poor during high-flow ventilation (6 litre min⁻¹ fresh-gas flow). It is unknown if accuracy improves when lower fresh-gas flow rates are used. We tested the hypothesis that tracheal temperature accuracy would improve with low-flow ventilation (1 litre min⁻¹ fresh-gas flow). We studied 20 ASA Physical Status I and II patients undergoing general anaesthesia for lower abdominal surgery. Deep body temperatures were measured at the middle of the sternum using a Coretemp “deep-tissue” thermometer. Tracheal temperatures were monitored from thermistors incorporated into the tracheal tube cuffs. Oesophageal temperatures were measured from thermocouples incorporated into stethoscopes positioned at the point of maximal heart sounds. Sternal temperature correlated reasonably well with distal oesophageal temperatures, both being within the 0.5°C cut-off for accuracy and precision. Tracheal temperatures were lower than oesophageal temperatures during both high- and low-flow ventilation. Tracheal temperatures were 0.7°C less during high-flow ventilation and 0.9°C less during low-flow ventilation. The precision in both cases was adequate. We conclude that tracheal temperatures were insufficiently accurate for routine clinical use, even when fresh-gas flow was restricted to 1 litre min⁻¹. In contrast, the deep temperatures were sufficiently accurate and precise for routine clinical use. (Br. J. Anaesth. 1998, 81: 171–175)

Keywords: Equipment, deep-tissue thermometer; measurement, fresh-gas flow; temperature, core; temperature, deep; temperature, measurement; temperature, tracheal

Perioperative thermal perturbations are common. Anaesthesia inhibits normal temperature control and this and exposure to a cold environment causes hypothermia. The initial decrease in core temperature, caused by a core-to-peripheral redistribution of body heat, is followed by net loss of heat to the environment. Hypothermia may be induced therapeutically because only 1–3°C reduction in core temperature provides substantial protection against cerebral ischaemia. Conversely, mild hypothermia is associated with adverse outcomes including morbid cardiac events, coagulopathy, prolonged post-anesthetic recovery, prolonged hospitalization and an increase in the incidence of surgical wound infection. Methods are now available to induce or prevent intraoperative hypothermia. Increased perioperative temperatures are also common.

Continuous core temperature monitoring is now standard practice during general anaesthesia. The tympanic membrane, distal oesophagus, pulmonary artery, and nasopharynx are generally considered reliable. Tracheal temperatures have been proposed as a convenient alternative. A critical aspect of this technique is positioning the temperature sensor on the patient side of the tracheal tube cuff, thereby limiting direct cooling by ventilatory gases. Despite this precaution, the accuracy of this site is relatively poor during high-flow ventilation (6 litre min⁻¹ fresh-gas flow). The accuracy of tracheal temperatures when lower fresh-gas flow rates are used is unknown. We tested the hypothesis that tracheal temperature accuracy would improve with low-flow ventilation and then be sufficiently accurate for routine use.

“Deep” sternal temperature has also proven sufficiently accurate for clinical use; this method depends on a technique developed by Fox and subsequently refined by Togawa. As Fox introduced originally “deep” sternal temperature as a core temperature not under general anaesthesia, we also tested the hypothesis that “deep” sternal temperature would improve its accuracy under low flow in a breathing system compared with high flow, because the lung and respiratory tracts connected to a breathing circuit are located underneath the sternum.

Methods

With approval of the Ethics Committee of the Yamanashi Medical University Hospital, we studied 20 ASA Physical Status I and II patients undergoing lower abdominal gynaecological surgery expected to last at least 2 h. Medication before anaesthesia consisted of atropine 0.5 mg and midazolam 1.5–2.0 mg.
administered i.m. General anaesthesia was induced with propofol 2 mg kg\(^{-1}\); vecuronium bromide was then given to facilitate tracheal intubation. A Trachelon tracheal tube (Terumo Corp., Tokyo, Japan) was inserted and positioned using standard clinical criteria (with the cuff passed 1 cm beyond the vocal cords under direct visualization). The tracheal cuff was inflated sufficiently to prevent gas leak at a sustained pulmonary pressure of 30 cm H\(_2\)O.

General anesthesia was maintained with isoflurane (1.0–3.0%) in nitrous oxide. The lungs of 10 patients who were randomly assigned, were mechanically ventilated using a partial re-breathing system (Modulus CD, Ohmeda, Liberty Corner, NJ, USA), at a fresh-gas flow rate of 6 litre min\(^{-1}\); the lungs of 10 others were ventilated with a fresh-gas flow rate of 1 litre min\(^{-1}\), to maintain end-tidal \(\text{P}_{\text{CO}_2}\) near 35 mm Hg. Additional vecuronium was administered, as needed, to maintain 1–2 twitches in response to supramaximal electrical stimulation of the ulnar nerve at the wrist. Respiratory gases were not warmed or humidified. A full-length circulating-water mattress heated to 38°C was positioned under each patient. I.v. fluids were warmed to 37°C and ambient room temperature was maintained near 23°C. A single layer of standard surgical draping covered each patient.

Deep body temperature was measured at the middle of the sternum using a Caretemp “deep-tissue” thermometer (Terumo Corp., Tokyo, Japan). The sensor element, 2.5 cm in diameter, was fixed securely with tape at the time of anaesthetic induction. Tracheal temperature was monitored from thermistors incorporated into the tracheal tube cuff (Terumo Corp.). Distal oesophageal temperature was measured from a thermocouple incorporated into the oesophageal stethoscope (Mallinckrodt Anaesthesiology Products, Inc., St. Louis, MO, USA). The stethoscope was positioned at the point of maximal heart sounds. Temperatures were recorded at 15-min intervals, starting 15 min after induction of anaesthesia.

Distal oesophageal temperature was considered the reference value. Temperatures at the other two sites were compared with oesophageal temperature using regression and Bland and Altman analyses.\(^{22}\) We decided \textit{a priori} that an accuracy (mean difference between reference and test temperatures) and precision (standard deviation of the difference) of 0.5°C was clinically adequate. The limit of 0.5°C was chosen because this variation is typical for other commonly used temperature measuring sites such as the axilla and mouth,\(^{23,24}\) and because we have used this value previously. Results are expressed as means (SD and range).

### Results

Characteristics of the patients whose lungs were ventilated with high- and low-fresh gas flows were comparable (table 1). Oesophageal temperatures ranged from 34.5 to 37.3°C. Sternal temperature correlated reasonably well with distal oesophageal temperatures, both being within the 0.5°C cut-off for accuracy and precision. Fresh-gas flow did not much influence the accuracy of either site. The correlation between tracheal and oesophageal temperatures was relatively poor during high-flow ventilation, and no better when fresh-gas flow was restricted to 1 litre min\(^{-1}\) (table 2, figs. 1 and 2).

### Discussion

Tracheal temperatures were not especially accurate, having a mean offset (reference minus tracheal temperature) of 0.7°C during high-flow ventilation. This result is consistent with previous observations.\(^{19}\) However, the offset remained high (0.9°C) during low-flow ventilation. We thus failed to confirm our hypothesis that a fresh-gas flow of only 1 litre min\(^{-1}\) would improve the accuracy of this measurement site. Interestingly, the precision of tracheal temperature measurements was acceptable with either high- or low-flow ventilation. These data suggest that tracheal temperature measurements are not especially variable, but that they consistently underestimate core temperature by 0.7–0.9°C. The site might thus yet prove useful if an appropriate compensation is built into the tracheal temperature monitoring system.\(^{25}\)

A fresh-gas flow of only 1 litre min\(^{-1}\) significantly increases airway temperature.\(^{26}\) However, a simple heat- and moisture-exchanger increases gas temperature considerably more.\(^{27}\) Active airway heating and humidification, naturally, increases ventilatory gas temperature still more.\(^{28}\) It seems likely that tracheal temperatures will better approximate core temperature in patients given passive or active gas conditioning. However, this potential accuracy improvement is itself problematic because different offset compensations would be required depending on the type of airway heating used.

Although the same breathing system was used with soda-lime for both low- and high-flow groups, the physical conditions such as temperature and relative humidity of both high- and low-flow inspired gases would differ. With a low-flow rate, oesophageal temperatures should be higher than with a high-flow rate because heat loss from the gas should be less. This could explain why at “low flow” the differences in both cases were greater than at high flow in figs 2 (A) and 2.

### Table 1

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BSA (m(^2))</th>
<th>LBM (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High flow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>56 (12)</td>
<td>156 (7)</td>
<td>55 (7)</td>
<td>1.6 (0.1)</td>
<td>44 (5)</td>
</tr>
<tr>
<td>[41–73]</td>
<td>[147–168]</td>
<td>[45–65]</td>
<td>[1.4–1.8]</td>
<td>[38–52]</td>
</tr>
<tr>
<td><strong>Low flow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>49 (13)</td>
<td>156 (7)</td>
<td>52 (7)</td>
<td>1.5 (0.1)</td>
<td>43 (5)</td>
</tr>
<tr>
<td>[27–67]</td>
<td>[147–166]</td>
<td>[39–62]</td>
<td>[1.3–1.7]</td>
<td>[34–49]</td>
</tr>
</tbody>
</table>
In contrast, “deep” sternal temperature correlates well with oesophageal temperature even when the respiratory tract was ventilated with high-gas flow.

Deep temperature measurements are based on heat flux. The system, in essence, consists of a heater positioned over a thermal flux transducer. The heater is then servo-controlled to null heat flux. Without a flow of heat across the transducer, the second law of thermodynamics specifies that temperatures must be equal on each side of the transducer (that is, heater and skin). So long as one is willing to assume an infinitely wide transducer/heater disk, the same logic applies to the tissue planes under the monitor; each must also be at the same temperature otherwise heat would accumulate in one region, again violating the second law. Of course the disk is not infinitely wide and convective flow of heat perturbs the theoretical thermal steady state.

Nevertheless, deep temperature monitors usually measure tissue temperature adequately to a depth of roughly 2 cm. Over the sternum, this depth apparently is sufficient to register core temperature. Deep temperatures proved sufficiently accurate for routine clinical use, having an accuracy and precision within 0.5 °C under both study conditions. This result is consistent with previous observations. Although Fox published his first article regarding “deep” temperature systems in 1970, only Japanese anaesthetists have tested its clinical usefulness. Because the monitoring system using his theory is only commercially available in Japan, we intend to investigate its accuracy under various clinical situations.

We used oesophageal temperature as a reference temperature. The temperature probe was incorporated into an oesophageal stethoscope. We checked the accuracy of the temperature probe location using auscultation of breath and heart sounds through the oesophageal stethoscope.

Despite a warming mattress, warmed i.v. fluids and warm ambient temperature, the initial redistribution of the heat inside the body caused a wide range of variation in core temperature, between 34.5 and 37.3 °C, so we had a wide range of core temperature for this study.

An accuracy of 0.5 °C among the main reference and tracheal or “deep” temperatures was chosen, from previous papers and our experience. The number of patients needed for the study was determined by power analysis using this limit of this accuracy.

### Table 2
Distal oesophageal temperature compared with “deep sternal” and tracheal temperatures during high- and low-flow anaesthesia. See fig. 1 for the regression lines and fig. 2 for the mean (SD) of the differences as outlined in the Bland-Altman plots.

<table>
<thead>
<tr>
<th>Gas flow</th>
<th>T_\text{sternum}</th>
<th>T_\text{trachea}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>$r^2$</td>
<td>0.72</td>
<td>0.85</td>
</tr>
<tr>
<td>Slope</td>
<td>0.93</td>
<td>0.97</td>
</tr>
<tr>
<td>Mean (°C)</td>
<td>0.0</td>
<td>0.5</td>
</tr>
<tr>
<td>SD (°C)</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

![Figure 1](image_url)  
*Figure 1* Regression comparison of distal oesophageal temperature with “deep sternal” (A) and tracheal (B) temperatures during high- (upper panel) and low- (lower panel) fresh-gas flows. See table 2 for regression slopes and coefficients.
In summary, we compared distal oesophageal temperature with “deep sternal” and tracheal temperatures in 20 patients undergoing general anaesthesia with high- or low-flow ventilation for gynaecological surgery. As in previous studies, deep temperatures were sufficiently accurate and precise for routine clinical use. Tracheal temperatures, in contrast, were insufficiently accurate for routine clinical use, even when fresh-gas flow was restricted to 1 litre min⁻¹.

Acknowledgements

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References


Figure 2  Bland and Altman comparison of distal oesophageal temperature with “deep sternal” (A) and tracheal (B) temperatures during high- (upper panel) and low- (lower panel) fresh-gas flows. The vertical axis is the difference between oesophageal and the test site. Mean temperature on the horizontal axis refers to the average between oesophageal and test temperatures at each measurement time. See table 2 for mean (sd) offsets.