Noninvasive Temperature Monitoring in Postanesthesia Care Units

Geoffrey E. Langham, B.S., Ankit Maheshwari, M.D.,† Kevin Contrera,‡ Jing You, M.S.,§ Edward Mascha, Ph.D.,‖ Daniel I. Sessler, M.D.#*

Background: Initial postoperative core temperature is a physician and hospital performance measure. However, the extent to which core temperature changes during emergence from anesthesia and transport from the operating room to the postanesthesia care unit (PACU) remains unknown. Similarly, the accuracy of many noninvasive temperature-monitoring methods used in the PACU has yet to be quantified. This study, therefore, quantified the change in core temperature occurring during emergence and transport and evaluated the accuracy and precision of eight noninvasive thermometers in the PACU.

Methods: In 50 patients having laparoscopic surgery, the authors measured temperatures upon PACU arrival and 30 and 60 min thereafter. Monitoring methods included oral, axillary, temporal artery, forehead skin-surface, forehead liquid-crystal display, infrared aural canal, deep forehead, and deep chest. Bladder temperature was used as the reference and was also measured at the end of surgery. The primary outcome was agreement between individual temperatures from each method and bladder temperature in the PACU. *A priori*, the authors chose 0.5°C as a clinically important temperature deviation.

Results: Bladder temperature increased 0.2 ± 0.3°C (95% confidence interval 0.1 to 0.3°C), $P < 0.001$, during transport. None of the tested noninvasive thermometers was consistently within 0.5°C of bladder temperature. However, oral, deep forehead, and temporal artery temperatures were significantly better than other methods and agreed reasonably well with bladder temperature.

Conclusions: Invasive temperature monitoring available intraoperatively is more accurate than any generally available postoperative methods. Physician performance measures should therefore not be based exclusively on postoperative temperatures. Among the generally available postoperative monitoring methods, electronic oral thermometry appears to be the best.

* Medical Student, School of Medicine, Case Western Reserve University; † Resident in Anesthesiology, Anesthesiology Institute, Cleveland Clinic; ‡ Research Assistant, # Professor and Chair, Department of Outcomes Research, Cleveland Clinic; § Biostatistician, ‖ Staff Biostatistician, Departments of Quantitative Health Sciences and Outcomes Research, Cleveland Clinic.

Address correspondence to Dr. Sessler: Department of Outcomes Research, Cleveland Clinic, 9500 Euclid Avenue—P77, Cleveland, Ohio, 44195. DS@OR.org, www.or.org. Information on purchasing reprints may be found at www.anesthesiology.org or on the masthead page at the beginning of this issue. ANESTHESIOLOGY's articles are made freely accessible to all readers, for personal use only, 6 months from the cover date of the issue.

** Specifications Manual for National Hospital Inpatient Quality Measures. SCIP-Inf-7: Colorectal Surgery Patients with Immediate Postoperative Normothermia, version 2.6b. Available at: http://www.jointcommission.org/PerformanceMeasurement/Performance Measurement/Current+NHQM+Manual.htm; accessed May 12, 2009.

†† Specifications Manual for National Hospital Inpatient Quality Measures. SCIP-Inf-10: Surgery Patients with Perioperative Temperature Management, version 3.0. Available at: http://www.jointcommission.org/PerformanceMeasurement/Performance Measurement/Future+NHQM+Manuals.htm. Accessed May 12, 2009.

‡‡ Quality Incentives in Anesthesiology – Perioperative Normothermia. Available at: http://www.asahq.org/Washington/P4P%20Normothermia%20Updated%20May 06%20.(3)pdf; accessed May 12, 2009.

PERIOPERATIVE hypothermia is common and leads to numerous adverse outcomes.[1–4] Hyperthermia is less frequent, but it can be more severe.[5,6] Monitoring core temperature during general anesthesia and maintaining intraoperative normothermia have thus become standard. However, most anesthesiologists have had the experience of caring for a patient who is normothermic (core temperature of at least 36°C) at the end of surgery, only to have a lower temperature obtained and documented in the postanesthesia care unit (PACU).

One potential explanation is that body temperature decreases between the last intraoperative and initial postoperative measurements. And in fact, hypothermia during transport, especially in patients having epidural anesthesia, has been reported. Hypothermia might develop because active warming must be discontinued for transport, and there is typically some environmental exposure associated with undraping and bandage application. On the other hand, discontinuing anesthesia disinhibits thermoregulatory control,[7,8] which should then help maintain normothermia.

A second potential explanation is simply that one of the temperature-monitoring methods is flawed. Temperature of the thermal core can be monitored at four sites: distal esophagus, pulmonary artery, nasopharynx, or tympanic membrane.[9] Monitoring at noncore sites, including the urinary bladder or rectum, reflects core temperature if certain precautions are taken.[10] Because core monitoring sites and most reliable near-core sites are somewhat invasive, core temperature is far more likely to be measured accurately during surgery than afterwards, when only noninvasive monitoring is generally acceptable.

Substantive divergence between intraoperative and postoperative temperature measurements would be important because the current version of Surgical Care Improvement Project, a major quality-tracking measure, requires that the initial postoperative temperature be normothermic in patients having colorectal surgery.** In contrast, a proposed version of this measure†† and a proposed American Society of Anesthesiologists Quality Incentive concerning perioperative normothermia‡‡ include all surgical patients and would be met if any temperature greater than or equal to 36.0°C is achieved in the period from 30 min before the end of anesthesia until 15 min after the end of anesthesia or if effective active warming systems are used. It is thus of considerable interest to know what temperature changes occur in patients during emergence from anesthesia and transport from the operating room to the PACU and which

noninvasive thermometers are sufficiently accurate for use in PACU patients.

Temporal artery,[11,12] infrared aural canal,[13,14] and skin-surface[15,16] thermometers have generally performed poorly in previous studies, whereas oral[17] and axillary[14,18] methods reflect core temperatures only in certain situations. Deep thermometry is a well-validated method that involves a servo-controlled heated sensor placed on the skin surface of the forehead or sternum.[19] Previous studies involving these devices have focused on other clinical settings, compared a single thermometer to another, or used a noncore site as the reference value. We therefore quantified the change in core temperature occurring during emergence and transport and evaluated the accuracy and precision of eight noninvasive thermometers suitable for the PACU.

Materials and Methods

With approval of the Cleveland Clinic Institutional Review Board (Cleveland, Ohio) and written informed consent, 50 patients scheduled for laparoscopic surgery were enrolled between January and September 2008. Exclusion criteria included age less than 18 yr or greater than 80 yr, American Society of Anesthesiologists Physical Status greater than 3, presence of a preexisting nasogastric tube, presence of upper esophageal disease other than gastroesophageal reflux, and infection or rash present at the forehead, mouth, or ear. Patients in whom bispectral index monitoring was planned were excluded because our protocol required full access to the forehead.

The following devices were used:

Foley catheter with thermistor (Mon-a-therm Foley-Temp; Mallinckrodt Anesthesiology Products, St. Louis, MO), which was considered our reference core temperature; esophageal stethoscope with thermistor (Mon-a-therm EST); temporal artery thermometer (TemporalScanner TAT-5000; Exergen, Boston, MA); infrared aural canal thermometer (FirstTemp Genius 3000A; Kendall, Mansfield, MA); skin-surface thermocouple (Mon-a-therm 6130); liquid-crystal display strip (Crystaline Moving Line; Sharn, Tampa, FL); electronic thermometer (IVAC TempPlus II 2080A; Cardinal, Dublin, OH); deep thermometer (CoreTemp CTM-205 with a PD-51 probe; Terumo, Tokyo, Japan).

Deep thermometry is based on a technique developed by Fox et al.[20,21] and refined by Togawa et al.[22] The general approach is to use a servo-controlled heater to null cutaneous heat flux, and then make the assumption that subcutaneous temperature, which reflects core temperature in specific locations, is equal to heater temperature. The system has generally proven reliable[19,23] and is used in Japan; it is approved by the United States Food and Drug Administration, but it has not generally been commercially available in the United States.

General endotracheal anesthetic management was at the discretion of the attending anesthesiologist. Underbody forced-air warming blankets (Bair Hugger; Arizant, Eden Prairie, MN) were applied to all patients. Blankets or drapes did not cover the upper chest, face, or head.

After induction of general anesthesia and tracheal intubation, a Foley catheter was inserted into the urinary bladder (per clinical routine for laparoscopic surgery) and an esophageal stethoscope was positioned in the distal esophagus. The investigator placed a liquid-crystal display strip superior to one eyebrow and a thermocouple onto the ipsilateral superior forehead. One deep sensor was positioned on the contralateral side of the forehead, another was positioned on the superior sternum, and each was secured with Tegaderm adhesive (3M, St. Paul, MN). All forehead sensors were separated by at least 2 cm.

The esophageal stethoscope was removed at the end of surgery. All other temperature monitoring continued. A disposable probe cover of the electronic thermometer was left in the axilla during recovery. The Foley catheter was removed after the study period at the discretion of the attending surgeon. PACU temperature was thermostatically controlled to approximately 23°C.

Measurements

Morphometric and demographic characteristics of the participants were recorded. Perioperative variables, including surgical procedure, duration of surgery, and ambient temperature, were recorded. Bladder and esophageal temperatures were measured when the esophageal stethoscope was removed before extubation.

Within 5 min of arrival in the PACU, temperatures were recorded with each of the systems described above except the removed esophageal probe. Temperatures were again recorded with each system 30 and 60 min thereafter. All measurements at each time were made within a 5-min interval and were based on a single determination with each device. Measurements with the temporal artery, infrared aural canal, and electronic thermometers (oral and axillary) were made according to manufacturer instructions. Infrared aural canal measurements were made in each ear.

Statistical Analysis

The primary outcome was agreement between temperatures from each method and bladder temperature. *A priori*, we chose a clinically important temperature deviation of 0.5°C. This value has been used in previous studies,[11,16] is similar to the variation between core temperature-monitoring sites,[9,18] and approximates the normal circadian variation.[24] We considered a method to be equivalent to bladder monitoring if its estimated 95% limits of agreement with bladder temperature were within 0.5°C and a 95% proportion of

its measurements were within 0.5°C of bladder temperature.

The study was designed with 50 patients, which provided enough data to create a 95% confidence interval (CI) with a width of 0.11 for a Pearson correlation of 0.9, and provided enough data to create a 95% CI for the proportion of measurements within 0.5°C of reference with a width of 0.55 standard deviations (SD).

Data from the left- and right-sided measurements from the infrared aural canal thermometer correlated highly; both sides were used for analysis. Per manufacturer's recommendation, measurements from the skin-surface thermocouple were adjusted by adding 2°C.

First, individual differences (bias) between measurements and the reference were calculated for each method. Individual differences were summarized across patients with mean and SD of the bias using the Bland-Altman repeated measurement data formula[25] to adjust for within-patient correlation. Then, Bland-Altman plots of individual differences of measurements *versus* the average of each pair of measurements were generated to show agreement with the reference as a function of the range of differences.

Second, the proportion of measurements for each method within 0.5°C of the reference was calculated, with 95% CI estimated using bootstrap resampling (with replacement) to account for the within-subject correlation. Specifically, each patient's entire data were resampled together, and the 2.5^{th} and 97.5^{th} percentiles based on 10,000 resamples from our original data were used to estimate each CI.

Third, Lin's concordance correlation coefficient (LCCC),[26] which summarizes both the bias from the 45-degree line of equality and the correlation with the reference, was calculated for each method. The CIs for the LCCCs were estimated using the same bootstrap percentile method as for the proportion within 0.5°C, using the same resampling runs.

All pairwise comparisons on the LCCC and proportion within 0.5°C among the ten methods (45 comparisons for each outcome) were conducted using z-tests. The numerator of each z-test (difference between methods) was obtained from the observed data, while the SE (denominator) was estimated using the SD across the bootstrap resamples. P values were adjusted for multiple comparisons using the Bonferroni step-down correction, less conservative than the traditional Bonferroni correction.

The temperature change occurring during emergence and transport between the operating room and PACU was calculated as the difference in bladder temperature between the initial PACU temperature and the final intraoperative temperature. The mean change was assessed using a paired *t* test.

R statistical software version 2.7.2 (The R Foundation for Statistical Computing, Vienna, Austria) and SAS 9.2

Table 1. Demographic, Morphometric, and Perioperative Characteristics, n = 50

Age, yr	57 ± 14
Height, cm	171 ± 10
Weight, kg	80 ± 17
Sex, male/female	24/26
ASA physical status, 1/2/3	4/20/26
Ambient temperature in OR, °C	21.7 ± 1.1
Ambient temperature in PACU, °C	23.6 ± 0.8
Duration of surgery, h	3.1 ± 1.4
Type of surgery	
Urologic	29 (58)
General	15 (30)
Colorectal	5 (10)
Gynecologic	1 (2)
Patient position during surgery	
Lateral	33 (66)
Supine	14 (28)
Lithotomy	3 (6)

Data presented as mean $\pm$ SD or no. (%).

ASA = American Society of Anesthesiologists; OR = operating room; PACU = postanesthesia care unit.

software (SAS Institute, Cary, NC) were used for all analyses. The overall significance level was 0.05 for the pairwise comparisons. All tests were 2-tailed. Data are reported as means $\pm$ SD.

Results

Fifty patients were enrolled, and all completed the study. Demographic, morphometric, and perioperative variables are displayed in table 1.

Bladder temperatures ranged from 34.0 to 38.6°C during the intraoperative period and from 34.7 to 38.1°C during the postoperative period. Bladder temperature at the end of surgery averaged 36.1 ± 0.7°C. Bladder and distal esophageal temperatures agreed very well, with 95% limits of agreement estimated at −0.56 to 0.45°C and LCCC of 0.92 (0.86, 0.95). Bladder temperature was only 0.06 ± 0.26°C less than esophageal temperature.

Between the final intraoperative measurement and arrival in the PACU, bladder temperature increased 0.2 ± 0.3°C, 95% CI 0.13 to 0.29°C, $P < 0.001$ (fig. 1). The average time elapsed between removal of the esophageal stethoscope and arrival in the PACU was 30 ± 12 min.

Scatter plots for each method *versus* the bladder temperature are shown in figure 2. Bland-Altman plots of differences from bladder temperature *versus* average of method and bladder temperature are shown in figure 3. Agreement for any particular method *versus* the bladder temperature did not vary over the range of temperatures.

The observed agreement between each method and bladder temperature in the PACU is given in table 2. Electronic oral thermometry was the most accurate and reliable device compared to the reference, with mean (SD) difference of −0.25°C (0.38°C) and proportion within 0.5°C of 81% (95% CI 73–89). The LCCC com-
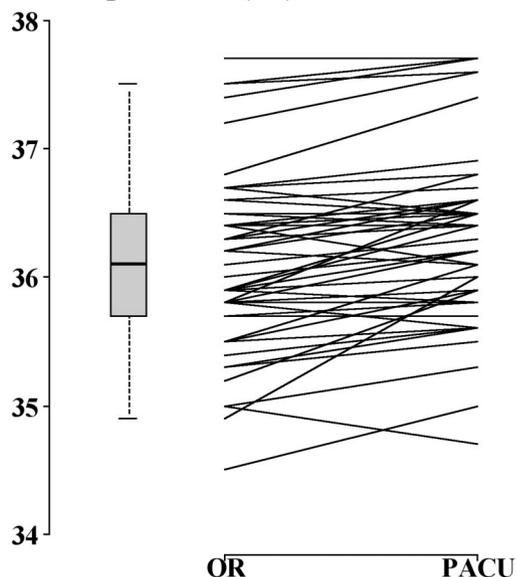
Core Temperature (°C)

Fig. 1. Individual changes in bladder temperature from the operating room (OR) at the end of surgery until arrival in the postanesthesia care unit (PACU). Box plots of the final measurement in the OR and temperature upon arrival in the PACU. The *middle*, *upper edge*, and the *lower edge* of the box indicate the 50th, 75th, and 25th percentile of the data set. The ends of the *vertical lines* indicate 1.5 times the interquartile range. The difference averaged 0.2 ± 0.3°C (95% confidence interval 0.13 to 0.29°C), $P < 0.001$. The average time elapsed between removal of the esophageal stethoscope and arrival in the PACU was 30 ± 12 min.

pared to the reference was 0.79 (95% CI 0.69–0.86), which was significantly better than all of the other methods. In table 2, we group the ten pairs of methods such that there are no statistically significant differences within group for each of the LCCC and proportion within 0.5°C outcomes.

Discussion

Although there are reasons that core temperature might decrease between the end of surgery and arrival in the PACU, it is actually unsurprising that discontinuation of general anesthesia would normally increase core temperature. Anesthetics profoundly reduce the thresholds (triggering core temperatures) for arteriovenous shunt constriction and shivering, the primary cold defenses in humans.[27,28] Unwarmed surgical patients nearly always become hypothermic,[29] initially from a core-to-peripheral redistribution of body heat,[30] and subsequently from heat loss exceeding metabolic heat production.[29] However, anesthetic-induced impairment of thermoregulatory control appears to depend on instantaneous drug concentrations; thermoregulatory control thus recovers immediately as anesthetic concentrations decrease towards zero during emergence.[8]

Key to interpreting this finding is that, although perioperative temperatures of at least 36°C are generally considered "normothermic," approximately 36°C — as in our patients — is not really normal. Core temperatures in humans usually vary sinusoidally from approximately 36.5 to 37.5°C, with a periodicity of 24 h and a peak temperature near 3:00 PM.[24] At times when most elective surgery ends, core temperature would thus normally be well above 36°C. It therefore follows that disinhibition of thermoregulatory control associated with emergence from anesthesia would invoke mechanisms to augment core temperature. Thermoregulatory vasoconstriction is the first defense to recover (because it has a threshold about 1°C higher than shivering[27,28]), and it is effective in constraining metabolic heat to the core thermal compartment.[31,32]

Our results are consistent with the theory that postoperative recovery of thermoregulatory control augments
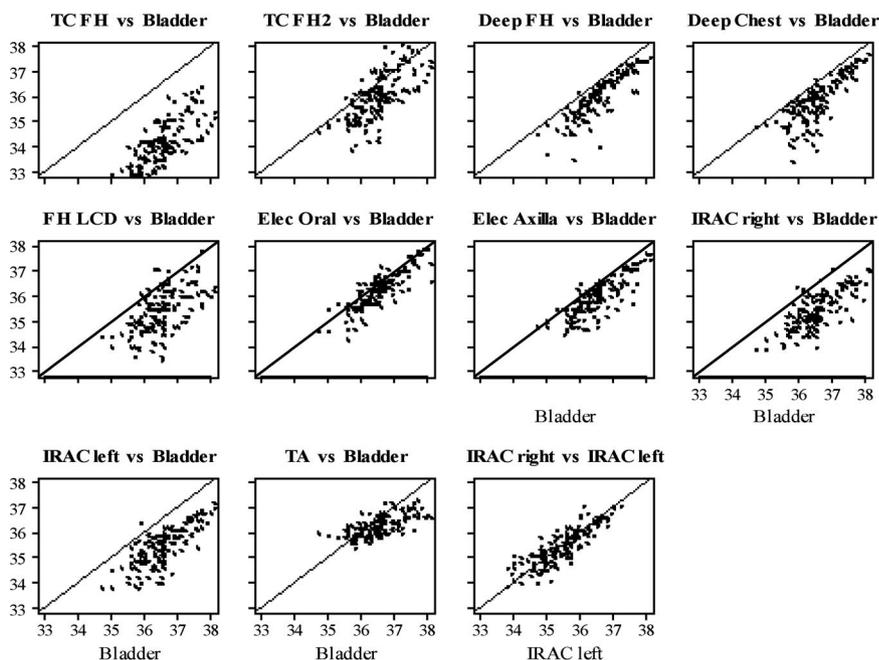

Fig. 2. Scatter plots of the ten temperature-monitoring methods against the reference method, and the two sides of infrared aural canal method, including the line of equality. Deep chest = deep temperature with a 7-cm probe on the chest; Deep FH = deep temperature with a 4-cm probe on the forehead; Elec Axilla = axilla with electronic thermometer; Elec Oral = posterior sublingual pocket with electronic thermometer; FH LCD = forehead liquid-crystal display; IRAC = infrared aural canal; TA = temporal artery with an electronic scanning thermometer; TC FH = forehead skin thermocouple; TC FH2 = TC FH plus 2°C.
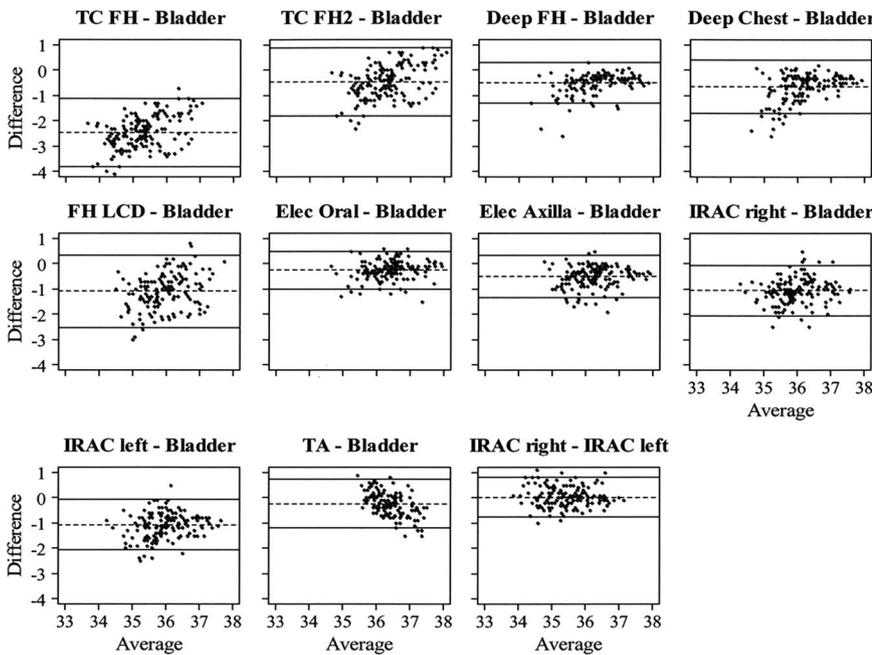
Fig. 3. Bland-Altman plots for each method *versus* bladder temperature, and the two sides of infrared aural canal method. On the *x axis* is the average of the measurement from method and bladder. On the *y axis* is the difference of the measurement from method and bladder. *Dashed line* shows mean bias, and *solid lines* show 95% limits of agreement. Deep chest = deep temperature with a 7-cm probe on the chest; Deep FH = deep temperature with a 4-cm probe on the forehead; Elec Axilla = axilla with electronic thermometer; Elec Oral = posterior sublingual pocket with electronic thermometer; FH LCD = forehead liquid-crystal display; IRAC = infrared aural canal; TA = temporal artery with an electronic scanning thermometer; TC FH = forehead skin thermocouple; TC FH2 = TC FH plus 2°C.

core temperature. In the approximately 30-min interval between the final intraoperative measurement and arrival in the PACU, bladder temperature increased 0.2 ± 0.3°C. Although not a large amount, the increase was consistent and highly statistically significant. It is thus clear that core temperatures do not generally decrease during this period as often supposed.

None of the temperature-monitoring systems fully met our *a priori* criteria of having 95% limits of agreement with bladder temperature within 0.5°C and a 95% proportion of its measurements within 0.5°C of bladder temperature. However, oral, deep forehead, and tempo-

ral artery temperatures correlated best with bladder temperature, with about 70–80% of all measurement pairs differing by no more than 0.5°C. This level of accuracy is probably suitable for postoperative clinical use. However, deep thermometry has not generally been commercially available in the United States and remains in limited use outside of Japan.

The temporal artery thermometer correlated reasonably well with bladder temperature in our PACU patients. This finding is in marked contrast to a previous study by Suleman *et al.*[11] in which a different model of temporal artery thermometer performed poorly. How-

Table 2. PACU Agreement between the Methods and Reference

Comparison‡	Mean (SD)	95% Limits of Agreement*	Proportion of Differences within 0.5°C (95% CI)†	LCCC (95% CI)†
Compared with the reference (bladder) temperature				
Elec Oral	−0.25 (0.38)	(−1.00, 0.50)	0.81 (0.73–0.89)§	0.79 (0.69–0.86)§
Deep FH	−0.50 (0.41)	(−1.31, 0.31)	0.71 (0.62–0.80)§	0.68 (0.57–0.77) (2)‖
TA	−0.23 (0.50)	(−1.20, 0.75)	0.70 (0.60–0.80)§	0.53 (0.41–0.64)‖
Elec axilla	−0.50 (0.42)	(−1.34, 0.33)	0.61 (0.49–0.71)‖	0.64 (0.49–0.75)‖
Deep chest	−0.65 (0.53)	(−1.70, 0.40)	0.51 (0.39–0.63)‖	0.55 (0.41–0.68)‖
TC FH2	−0.46 (0.68)	(−1.81, 0.88)	0.46 (0.35–0.58)‖	0.56 (0.42–0.68)‖
IRAC right	−1.04 (0.51)	(−2.04, −0.04)	0.13 (0.05–0.21)#	0.34 (0.22–0.44)#
IRAC left	−1.06 (0.51)	(−2.06, −0.06)	0.13 (0.06–0.21)#	0.34 (0.22–0.44)#
FH LCD	−1.09 (0.73)	(−2.53, 0.35)	0.19 (0.10–0.29)#	0.27 (0.18–0.38)#
TC FH	−2.46 (0.68)	(−3.81, −1.12)	0.00 (0.00–0.00)	0.12 (0.08–0.16)
Between two references				
Bladder – esophageal	−0.06 (0.26)	(−0.56, 0.45)	0.96 (0.93–0.99)	0.92 (0.86–0.95)
IRAC right − IRAC left	0.02 (0.40)	(−0.76, 0.81)	0.83 (0.77–0.89)	0.85 (0.78–0.90)

* Bland-Altman limits of agreement for repeated measurement data,[25] adjusting for within-patient correlation; † 95% confidence intervals (CIs) were estimated using the percentile method based on 10,000 bootstrap resamples; ‡ all data were obtained postoperatively except for bladder versus esophagus; §‖#** groups of methods that do not differ significantly.

Deep chest = deep temperature with a 7-cm probe on the chest; Deep FH = deep temperature with a 4-cm probe on the forehead; Elec Axilla = axilla with electronic thermometer; Elec Oral = posterior sublingual pocket with electronic thermometer; FH LCD = forehead liquid-crystal display; IRAC = infrared aural canal; LCCC = Lin's concordance correlation coefficient; PACU = postanesthesia care unit; SD = standard deviation; TA = temporal artery with an electronic scanning thermometer; TC FH = forehead skin thermocouple; TC FH2 = TC FH plus 2°C.

ever, our results are consistent with those of Kimberger *et al.*,[12] who evaluated the same thermometer model in neurosurgical patients and found similar 95% limits of agreement between the device and bladder temperature. In both studies, however, temporal artery monitoring performed poorly in the context of detecting fever. Fever is an important postoperative complication that can warn of infection, allergic reactions, and mismatched blood transfusions. Additional validation would thus seem prudent before adopting temporal artery thermometry for routine postoperative use.

Axillary, deep chest, and forehead thermocouple with a 2°C offset performed at an intermediate level with about 45–60% of the measurement pairs differing by no more than 0.5°C. Although some clinicians might accept this level of accuracy, these measurement systems seem to offer little advantage over electronic oral temperatures. But in the occasional patient in whom oral temperatures are unsuitable, axillary temperatures would be a reasonable substitute. In contrast, infrared aural canal, forehead liquid-crystal, and forehead thermocouple temperatures differed substantially from bladder temperature, with less than 20% of the measurement pairs differing by no more than 0.5°C. These sites thus appear unsuitable for clinical use; in light of these results and previous similar data,[13,33,34] it seems unfortunate that infrared aural canal thermometers have become so popular.

Three reliable core temperature-monitoring sites are potentially available during most general anesthetics: distal esophagus, nasopharynx, and tympanic membrane. While particular sites may not be suitable in individual patients, it is the rare patient in whom none can be used. It is thus evident that core temperature can usually be accurately measured in most patients having general anesthesia. In contrast, core temperature can only be estimated in most postoperative patients. Performance measures should thus be based on the final intraoperative temperature measurement or on either the final intraoperative temperature or initial postoperative temperature — and only then if postoperative temperature is monitored at a well-validated site such as the mouth.

Our final intraoperative temperature measurement and the initial measurement in the PACU differed by 30 min. We note, however, that the final intraoperative measurement, per clinical routine, was well before the end of anesthesia. Furthermore, we allowed up to 5 min before making the initial PACU measurement. Actual transport time was thus considerably less than 30 min. Presumably, the increase in core temperature would be less in smaller periods, and greater if longer times elapse between the final operating room temperature measurement and the initial PACU measurement.

Bladder temperature is not considered one of the four reliable core sites because it lags core temperature during periods of rapid thermal flux such as cardiopulmo-

nary bypass.[35] A similar effect has been reported during noncardiac surgery, although with a smaller magnitude.[36] However, none of the conventional core sites was available to us postoperatively, just as they are not routinely available in clinical practice. We therefore used bladder temperature as our reference in the postoperative period. To confirm that our assumption of near-equivalence was appropriate, we measured both bladder and esophageal temperatures during surgery. As expected, the values were similar, suggesting that bladder temperature was a reliable core reference under the conditions of our study.

A newer model of the deep thermometer is now available, the CM-210. Although based on the same thermodynamic and physiologic principle, the newer model may be more accurate than the one we evaluated.

In summary, core temperature does not decrease during the interval from the end of surgery until PACU admission. Instead, it increases slightly. The increase presumably results from disinhibition of thermoregulatory control and subsequent efforts to regain a normal core temperature, which is likely to be near 37°C at the time most elective operations end. None of the eight temperature-monitoring methods fully met our *a priori* requirement of being consistently within 0.5°C of bladder temperature. However, oral, deep forehead, and temporal artery temperatures correlated reasonably well with bladder temperature, and they appear suitable for clinical use. Deep thermometry has not been generally available in the United States, and the temporal artery thermometer has poorly detected fever in previous studies. Electronic oral temperatures thus appear to be the best approach for routine postoperative use. Axillary temperature is a reasonable substitute in the occasional patient in whom oral temperatures are unsuitable. Intraoperative temperature monitoring can include invasive sites, so intraoperative temperatures are generally likely to be more accurate than postoperative measurements and would thus be a more reliable basis for performance measures.

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