Accuracy of non-invasive body temperature measurement methods in critically ill patients: a prospective, bicentric, observational study

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Body temperature (BT) is strictly regulated¹⁻³ and is a key vital sign. In critically ill patients, abnormal BT is associated with adverse clinical outcomes.^{4,5} Moreover, BT abnormalities are used to identify specific phenotypes of immune reaction to infection⁶ and to evaluate response to interventions (eg, antibiotic or anti-inflammatory therapies).⁷ Accordingly, prompt recognition and monitoring of BT perturbations is fundamental in the management of traumatic brain injury⁸ and cardiac arrest⁹ and also as an early warning sign of critically ill patients in general.

The pulmonary artery catheter is considered the gold standard for the measurement of core temperature,¹⁰ but its use is limited and declining.^{11,12} Compared with pulmonary artery catheter, temperature-sensing intra-urinary bladder catheters, oesophageal and nasopharyngeal probes may represent less invasive methods of core BT measurement. However, their use is limited in critical care practice due to urine output dependence and easy displacement. Thus, non-invasive BT measurement methods (axillary thermometer, tympanic infrared and temporal scanner) have become common.^{2,13-15} But their accuracy in estimating core BT in ICU patients is uncertain.^{16,17} Moreover, a recent survey¹⁸ highlighted a lack of agreement on the preferred BT measurement methods between doctors and nurses and lack of protocol governance among Australian and New Zealand ICUs.

Accordingly, we sought to investigate the accuracy of the axillary chemical dot, tympanic infrared and temporal scanner methods in estimating core temperature in critically ill patients admitted to the ICU. The primary hypothesis was that all three non-invasive BT measurement methods would show low accuracy in estimating core BT compared with invasive methods and that these accuracies would differ from each other. The secondary hypothesis was that accuracy of each non-invasive BT measurement method would be influenced by clinical variables.

ABSTRACT

Objective: The accuracy of different non-invasive body temperature measurement methods in intensive care unit (ICU) patients is uncertain. We aimed to study the accuracy of three commonly used methods.

Design: Prospective observational study.

Setting: ICUs of two tertiary Australian hospitals.

Participants: Critically ill patients admitted to the ICU.

Interventions: Invasive (intravascular and intra-urinary bladder catheter) and non-invasive (axillary chemical dot, tympanic infrared, and temporal scanner) body temperature measurements were taken at study inclusion and every 4 hours for the following 72 hours.

Main outcome measures: Accuracy of non-invasive body temperature measurement methods was assessed by the Bland–Altman approach, accounting for repeated measurements and significant explanatory variables that were identified by regression analysis. Clinical adequacy was set at limits of agreement (LoA) of 1°C compared with core temperature.

Results: We studied 50 consecutive critically ill patients who were mainly admitted to the ICU after cardiac surgery. From over 375 observations, invasive core temperature (mostly pulmonary artery catheter) ranged from 33.9°C to 39°C. On average, the LoA between invasive and non-invasive measurements methods were about 3°C. The temporal scanner showed the worst performance in estimating core temperature (bias, 0.66°C; LoA, −1.23°C, +2.55°C), followed by tympanic infrared (bias, 0.44°C; LoA, −1.73°C, +2.61°C) and axillary chemical dot methods (bias, 0.32°C; LoA, −1.64°C, +2.28°C). No methods achieved clinical adequacy even accounting for significant explanatory variables.

Conclusions: The axillary chemical dot, tympanic infrared and temporal scanner methods are inaccurate measures of core temperature in ICU patients. These non-invasive methods appeared unreliable for use in ICU patients.

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Methods

The Ethics of Human Research Committee of the Austin Hospital approved the study and waived the need for informed consent (LNR/17/Austin/315) due to its implied observational nature.

Study design and population

We performed a prospective observational study in critically ill patients admitted to the ICU of two tertiary metropolitan hospitals (Austin Hospital and Warringal Hospital, Melbourne, VIC). We included patients who had a temperature-sensing intravascular (mostly pulmonary artery catheter) or intra-urinary bladder catheter, which was placed before the inclusion in the study by the treating physician. We excluded patients aged less than 18 years, patients with skin infection, and pregnant women.

BT measurement methods

Characteristics (manufacturer and other commercial details) of the BT measurement methods used in the study are reported in the Online Appendix, eTable1. All BT measurement methods were calibrated according to hospital protocols and manufacturer's specifications. We classified BT measurement methods as:

- **Invasive:** temperature-sensing intravascular or intra-urinary bladder catheters. Intravascular catheters included temperature-sensing vascular probe placed into the pulmonary artery or the femoral artery (pulse contour cardiac output, PiCCO). The correct position of the pulmonary artery catheter was as described.¹⁹
- **Non-invasive:** axillary chemical dot, temporal scanner and tympanic infrared methods.

Concurrent invasive and non-invasive BT measurements were taken by on-duty nurses at the inclusion in the study and every 4 hours for the following 72 hours, as per hospital protocol. Intra-urinary bladder temperature measurements were recorded only when an intravascular catheter was not in place. Due to analogue accuracy in estimating core temperature,²⁰ intra-urinary bladder and intravascular measurements were merged and reported as "invasive BT measurement methods".

Data collection

Patients' demographic data (age, sex, height and weight), cardiovascular comorbidities and main pathology at ICU admission were recorded. Concurrent haemodynamic parameters (blood pressure and heart rate), medications (sedatives, opioids, vasopressors and inotropes), fluid balance, artificial organ supports (mechanical ventilation, renal replacement therapy and extracorporeal membrane oxygenation), and warming or cooling interventions were recorded at each BT measurement time point.

Outcomes

The primary outcome of the study was the assessment of accuracy of non-invasive BT measurement methods in estimating core temperature and the relationship between axillary chemical dot, tympanic infrared and temporal scanner methods by the evaluation of:

- **Bias:** mean difference between temperature measured by invasive methods and either axillary chemical dot, tympanic infrared or temporal scanner. Bias was used to express accuracy, as fixed offset between BT measurements.
- **Limits of agreement (LoA):** 95% confidence interval (CI) of the differences between body temperature measured by invasive methods and either axillary chemical dot, tympanic infrared or temporal scanner.

Specifically, clinical accuracy was defined as bias between each method and the others within $\pm 0.2^{\circ}\text{C}$.¹⁶ Clinical adequacy was set at LoA of 1°C compared with core temperature.

A secondary outcome of the study was the evaluation of clinical conditions or interventions, which predicted bias and LoA between invasive and non-invasive BT measurements.

Statistical analysis

Continuous data are presented as mean (standard error; SE) or median (interquartile range; IQR), categorical data are summarised as number (percentage). After assessing the distribution of the data with the kernel density plot and the Kolmogorov–Smirnov test, the relationship between invasive and non-invasive methods was investigated with the Bland–Altman approach, by plotting differences versus means of paired core temperature (gold standard) and non-invasive (index methods) measurements.^{21–25}

To account for repeated measurements of BT in the same individual and adjust for significant explanatory clinical variables, mixed linear modelling was performed and patients' demographic characteristics, comorbidities, medications and extracorporeal organ supports were included in a multivariable model. Then, bias and LoA were adjusted for significant predictors of BT temperature. Finally, a multivariate analysis accounting for repeated measures was performed with the aim to explore the relationship between variables which were independently associated with BT and bias of non-invasive BT measurement methods in estimating core temperature. We analysed data using Stata/SE 13 (StataCorp, College Station, TX, USA) and SAS version 9.4 (SAS Institute Cary, NC, USA) while graphs were plotted using MS Excel 2017 (Microsoft, Seattle, WA). To increase the robustness of this study, a reduced two-sided *P* value of 0.01 was used to indicate statistical significance.

Table 1. Patients' demographic characteristics at inclusion

Variable	Patients
Total number of patients	50
Age (years), median (IQR)	68 (59–74)
Sex, male	35 (70%)
Weight (kg), median (IQR)	76.4 (70–95)
Height (cm), median (IQR)	170 (163–173)
APACHE III score, median (IQR)	40 (33–49)
Comorbidities	
Coronary artery disease	31 (62%)
Hypertension	27 (54%)
Dyslipidaemia	22 (44%)
Smoke	28 (56%)
Sedatives*	50 (100%)
Opioids	7 (14%)
Neuromuscular blockers	2 (4%)
Mechanical ventilation	47 (94%)
Haemodynamic support	
Vasopressors/inotropes	13 (26%)
Extracorporeal membrane oxygenation	1 (2%)
Renal replacement therapy	3 (6%)
Diagnosis at admission	
Cardiac surgery	44 (88%)
Respiratory failure	2 (4%)
Liver failure	1 (2%)
Intracranial haemorrhage	1 (2%)
Others	2 (4%)

APACHE = Acute Physiology and Chronic Health Evaluation; IQR = interquartile range. * Propofol, midazolam, dexmedetomidine

Results

Patients

A convenience sample of 50 consecutive critically ill patients ($n = 35$, 70% male) was included in the study. Demographic and clinical characteristics of all patients are shown in Table 1. Median age was 68 years (IQR, 59–74 years) and median APACHE III score was 40 (IQR, 33–49). The most frequent reason for ICU admission was cardiac surgery ($n = 44$, 88%). All patients were sedated ($N = 50$, 100%), most were mechanically ventilated ($n = 47$, 94%) and 13 patients (26%) were receiving vasopressor/inotropic support at study inclusion.

Primary outcome

Over 375 observations in 50 patients, core temperature measured by invasive BT measurement method ranged between 33.9°C and 39°C (Online Appendix, eTable 2). Non-invasive BT measurement methods systematically underestimated core temperature (Table 2). On average, the LoA between invasive and non-invasive BT measurements methods was about 3°C, with the temporal scanner methods showing the worst performance in estimating core temperature (bias, 0.66°C; LoA, −1.23°C, +2.55°C), followed by tympanic infrared (bias, 0.44°C; LoA, −1.73°C, +2.61°C) and the axillary chemical dot method (bias, 0.32°C; LoA, −1.64°C, +2.28°C). The axillary chemical dot and tympanic infrared had the lowest degree of bias and the largest LoA, which approximated 4°C. However, none of the non-invasive BT measurement methods showed clinically acceptable accuracy.

Secondary outcome

The regression model accounting for repeated measures of BT is presented in the Online Appendix, eTable 3. An independent and negative association was found between BT and propofol infusion, mechanical ventilation, neuromuscular blocker agents, renal replacement therapy, aortic surgery and active warming. After adjusting for significant covariates

Table 2. Accuracy of non-invasive measurement methods accounting for repeated measures

Methods	<i>n</i>	Mean difference, °C (95%CI)	95% Limits of agreement (lower, upper)	<i>P</i>
Invasive — axillary chemical dot	279	0.32 (0.21–0.43)	−1.64, 2.28	< 0.001
Invasive — temporal scanner	361	0.66 (0.56–0.76)	−1.23, 2.55	< 0.001
Invasive — tympanic infrared	285	0.44 (0.32–0.56)	−1.73, 2.61	< 0.001
Axillary chemical dot — temporal scanner	275	0.34 (0.24–0.44)	−1.34, 2.02	< 0.001
Axillary chemical dot — tympanic infrared	279	0.12 (0.01–0.24)	−1.86, 2.11	0.041
Tympanic — temporal	290	0.22 (0.11–0.33)	−1.70, 2.13	< 0.001

Figure 1. Bland–Altman plots of temperature measurements, accounting for repeated measures and adjusted for significant covariates: (A) invasive and axillary chemical dot method, (B) invasive and tympanic infrared method, and (C) invasive and temporal scanner method

Each coloured dot corresponds to mean (x-axis) and difference (y-axis) of paired invasive (gold standard) and non-invasive (index methods) measurements. Among horizontal dotted lines, the inner represents the mean difference (bias) and the outers represent the 95% CI of differences (limit of agreement) of paired invasive (gold standard) and non-invasive (index methods) measurements.

(Online Appendix, eTable 4), bias and LoA between invasive and non-invasive BT measurement methods were reduced (Online Appendix, eTable 5). However, none of the non-invasive BT measurement methods showed clinically acceptable accuracy in estimating core temperature. The corresponding Bland–Altman plots are represented in Figure 1, A–C. Moreover, we reported the deviation of each non-invasive BT measurements from invasive temperature (Online Appendix, eFigure 1, A–C).

The regression model exploring the relationship between explanatory variables of BT and bias between invasive and non-invasive BT measurement methods is presented in Table 3. None of the clinical variables included in the analysis showed significant association with bias either between core temperature and tympanic infrared or temporal scanner.

Axillary chemical dot failed to measure BT in 16 observations and was reported by nurses as non-readable. Tympanic infrared failed once in measuring BT (Online Appendix, eTable 2).

Discussion

Key findings

We assessed the accuracy of the axillary chemical dot, tympanic infrared and temporal scanner methods to estimate core temperature in ICU patients. Each of the non-invasive BT measurement methods showed wide LoA and inadequate clinical accuracy in estimating core temperature among an average of more than 300 paired observations. Moreover, each non-invasive BT measurement

Table 3. Predictors of bias between invasive and non-invasive body temperature measurement methods accounting for repeated measures

Model	Univariate analysis*			Multivariable analysis*		
	Estimate	95% CI (lower, upper)	P	Estimate	95% CI (lower, upper)	P
Fixed effect: invasive v axillary chemical dot						
Covariates						
Propofol	−0.001	−0.003, 0.001	0.15	−0.0001	−0.001, 0.001	0.98
Active warming	−0.16	−0.55, 0.23	0.42	−0.01	−0.37, 0.36	0.96
Mechanical ventilation	−0.24	−0.42, −0.07	0.007	−0.22	−0.39, −0.04	0.02
Neuromuscular blocking agents	−0.004	−0.33, 0.32	0.98	0.15	−0.15, 0.46	0.33
Renal replacement therapy	−0.05	−0.40, 0.30	0.79	−0.03	−0.35, 0.30	0.87
Aortic surgery	−0.34	−1.46, 0.77	0.55	−0.45	−1.54, 0.63	0.41
Enrolment time point	0.014	−0.002, 0.03	0.06	0.01	−0.002, 0.02	0.09
Fixed effect: invasive v tympanic infrared						
Covariates						
Propofol	0.0003	−0.002, 0.002	0.55	0.0003	−0.001, 0.001	0.53
Active warming	−0.12	−0.44, 0.20	0.48	−0.05	−0.35, 0.25	0.72
Mechanical ventilation	−0.04	−0.20, 0.13	0.65	−0.05	−0.21, 0.12	0.60
Neuromuscular blocking agents	0.17	−0.15, 0.48	0.30	0.21	−0.09, 0.51	0.17
Renal replacement therapy	−0.04	−0.39, 0.30	0.81	−0.05	−0.37, 0.27	0.75
Aortic surgery	−0.34	−1.14, 0.45	0.40	−0.36	−1.18, 0.46	0.39
Enrolment time point	−0.002	−0.02, 0.12	0.74	0.001	−0.01, 0.01	0.93
Fixed effect: invasive v temporal scanner						
Covariates						
Propofol	−0.002	−0.003, −0.001	0.01	−0.001	−0.002, 0.001	0.20
Active warming	−0.40	−0.71, −0.08	0.01	−0.31	−0.61, 0.01	0.045
Mechanical ventilation	−0.08	−0.23, 0.07	0.28	−0.01	−0.17, 0.15	0.88
Neuromuscular blocking agents	0.08	−0.33, 0.49	0.71	0.07	−0.29, 0.42	0.71
Renal replacement therapy	−0.02	−0.44, 0.40	0.93	0.01	−0.35, 0.38	0.94
Aortic surgery	−0.88	−1.37, −0.38	0.001	−0.72	−1.32, −0.11	0.02
Enrolment time point	0.014	−0.002, 0.03	0.08	0.004	−0.01, 0.02	0.58

method showed low agreement with other non-invasive methods. Finally, adjusting for explanatory variables of BT such as propofol infusion, mechanical ventilation, neuromuscular blocker agents, renal replacement therapy, aortic surgery and active warming only improved their accuracy to a limited degree.

Relationship to previous studies

Previous international guidelines published in 2008²⁶ suggested avoidance of axillary methods, temporal

scanner and chemical dot thermometers in ICU patients. However, such recommendations were only supported by observational studies^{27–31} with controversial findings and methodological problems. Specifically, there was lack of control for possible confounders such as device calibration, investigator skill assessment, method used, failure to use the Bland–Altman approach in estimating bias and LoA, and lack of adjustment for multiple within-subject measurement.³² Thus, these recommendations do not appear to have been widely adopted.

These shortcomings were further highlighted in an initial systematic review.¹⁶ In a further systematic review of 75 studies in adult and paediatric patients from different clinical settings (only 45% ICU), investigators concluded that peripheral thermometers do not have clinically acceptable accuracy, although high quality data were limited and study heterogeneity was significant. In a more recent systematic review of 13 studies in adult ICU patients, Cutuli and colleagues³² found that the majority of studies did not control for clinical confounders³³ or used suboptimal statistical methods.²¹⁻²⁴ Because of such limitations and the wide types of non-invasive thermometry used to assess BT, both systematic reviews^{16,32} could not synthesise the data available and/or obtain conclusive results. Given the above problems, we aimed to overcome such methodological issues.

Our findings are similar to and extend those of Moran et al,²⁰ who investigated the accuracy of tympanic infrared and axillary glass mercury thermometers in estimating core temperature in a cohort of critically ill patients. In their study, the accuracy of the axillary glass mercury method was superior to the tympanic infrared method. However, the authors did not specify whether non-invasive BT measurement methods had been calibrated before the commencement of the study and set tympanic infrared in "core mode". In our study, the tympanic infrared devices were unadjusted to assess core temperature according to the manufacturer algorithm⁴ (ear mode +1.04°C). However, such conversion would have only influenced the direction of the bias, while the magnitude of inaccuracy would have remained unchanged.

In contrast with our observations, Fulbrook and colleagues³⁴ reported that axillary chemical dots slightly underestimated core temperature compared with the tympanic infrared method. However, the authors only included a small number of patients and observations. More recently, Farnell et al²⁵ reported axillary chemical dot failures in seven of 160 BT measurements in 25 critically ill patients, which confirms the rate of "non-readable" strips seen in our study. In addition, axillary chemical dots appeared to show lower accuracy than the tympanic infrared method in estimating core temperature. However, as the authors did not account for repeated within-subject measurements, the robustness of such findings is unclear. Finally, Myny et al³⁵ argued in favour of a better accuracy for the temporal scanner in estimating core temperature in 57 critically ill patients. Yet, the number of observations was small and the participation of only one operator increased observer bias and limited external validity.

Clinical implications

The low accuracy of axillary chemical dot, tympanic infrared and temporal scanner methods in estimating

core temperature implies that these methods are clinically inadequate for ICU patients. Such implication is of importance for research in ICU patients with specific conditions (eg, suspected infection), for whom BT may represent an inclusion criterion. Moreover, the wide LoA imply that "average" adjustments upward of 0.5 or 1 degree are not helpful. In addition, the impact on bias and LoA of clinical explanatory variables implies that any link between these techniques and core temperature will markedly vary according to clinical circumstances. Finally, the high rate of failure for the chemical dot approach is of concern and implies limited applicability. In their aggregate, our findings imply that current non-invasive temperature measurement techniques are inappropriate and potentially misleading in many ICU patients.

Strengths and limitations

Our study has several strengths. First, we investigated the accuracy of the most widely used non-invasive BT measurement methods in ICU. Second, we used the Bland–Altman approach accounting for repeated within-subject measures, which allowed us to overcome methodological issues raised by previous systematic reviews.^{16,32} Third, we performed regression analysis to identify predictors of BT, which allowed us to explore the impact of clinical variables on temperature estimation. Nonetheless, our study carries some limitations. It was not blinded and on-duty bedside nurses may have been biased in their data collection. However, nurses were asked to measure BT as they do in daily clinical practice and we estimate that more than 100 nurses were involved in the study measurements, which gives our findings a robust level of external validity and makes systematic bias unlikely. We tested only few non-invasive BT measurement methods and our results do not apply to other types of thermometry such as the newest zero heat flux.^{36,37} However, such thermometers are of limited daily use because of their cost. We found wider LoA compared with previous articles in this field,³² supporting the limited use of non-invasive BT measurement methods in the ICU. However, this finding may be explained by the design of our study, which controlled for clinical confounders and adopted adequate statistical method to account for significant explanatory variables and multiple within-subject measurements. Finally, we merged different invasive BT methods into a single variable; however, previous evidence²⁰ investigated the accuracy of temperature-sensing urinary catheters in estimating core temperature and confirmed their negligible bias and LoA.

Conclusions

Non-invasive body temperature measurement techniques are inaccurate, show bias and have wide LoA in relation

to core temperature in ICU patients. Given the diagnostic and therapeutic importance of this vital sign in critically ill patients, the use of axillary chemical dot, tympanic infrared and temporal scanner methods appears suboptimal in the ICU.

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Competing interests

No relevant disclosures.

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