Accuracy of non-invasive body temperature measurement methods in adult patients admitted to the intensive care unit: a systematic review and meta-analysis

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ABSTRACT

Objective: Non-invasive thermometers are widely used in both clinical practice and trials to estimate core temperature. We aimed to investigate their accuracy and precision in patients admitted to the intensive care unit (ICU).
Study design: Systematic review and meta-analysis.
Data sources: We searched MEDLINE, EMBASE and the Cochrane Central Register of Controlled Trials to identify all relevant studies from 1966 to 2017. We selected published trials that reported the accuracy and precision of non-invasive peripheral thermometers (index test) in ICU patients compared with intravascular temperature measurement (reference test). The extracted data included the study design and setting, authors, study population, devices, and body temperature measurements.
Methods: Two reviewers performed the initial search, selected studies, and extracted data. Study quality was assessed using the QUADAS-2 tool. Pooled estimates of the mean bias between index and reference tests and the standard deviation of mean bias were synthesised using DerSimonian and Laird random effects meta-analyses.
Results: We included 13 cohort studies (632 patients, 105 375 measurements). Axillary, tympanic infrared and zero heat flux thermometers all underestimated intravascular temperature. Only oesophageal measurements showed clinically acceptable accuracy. We found an insufficient number of studies to assess precision for any technique. Study heterogeneity was high (99–100%). Risk of bias for the index test was unclear, mostly because of no device calibration or control for confounders.
Conclusions: Compared with the gold standard of intravascular temperature measurement, non-invasive peripheral thermometers have low accuracy. This makes their clinical and trial-related use in ICU patients unreliable and potentially misleading.

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Body temperature is a key vital sign in intensive care unit (ICU) practice due to its clinical implications.[1] Moreover, body temperature abnormalities are frequent in the ICU,[2] trigger interventions (eg, antibiotics), and allow prognostication.[3-7] Finally, targeting of specific body temperature levels has been a key feature of multiple studies in patients after cardiac arrest,[8-10] brain injury,[11-14] and infection[15-17] (Online Appendix, 1).

Body temperature is classified as "core", which refers to the temperature of organs, measured by invasive methods (eg, oesophageal probes), and "peripheral", which refers to the temperature of external body surfaces, measurable by non-invasive tools (eg, cutaneous)[18] (Online Appendix, 2). Intravascular thermometers are considered to be the gold standard for core body temperature measurement, although pulmonary artery catheter (PAC)[19] use is decreasing over time.[20,21] Other tools have been proposed for clinical use or trials.[22,23] Although invasive tools have been advised in severely ill patients,[24-26] peripheral thermometers are widely used in the ICU.[27] However, concerns about their low accuracy[28,29] and the impact of such possible inaccuracy on clinical management remain. Despite such concerns and the importance of accurate temperature measurement in ICU patients, the available evidence for these patients has never been systematically reviewed and analysed.

Accordingly, we aimed to survey the literature with the intention to systematically assess the accuracy and precision of both peripheral and invasive thermometers in the ICU.

Methods

Study protocol

The protocol for this systematic review and meta-analysis was published[30] before commencement and was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[31]

Search strategy

MEDLINE, EMBASE and the Cochrane Central Register of Controlled Trials were searched to identify relevant studies published from 1966 to 2017 (Online Appendix, 3). Electronic database searches were supplemented by hand-searching of reference lists of retrieved articles, previous reviews and international guidelines.

Study inclusion and exclusion criteria

We included observational studies and randomised controlled trials published in English in peer-reviewed journals. These studies were performed in adult (aged ≥ 18 years) ICU patients and investigated accuracy and precision of non-invasive peripheral and invasive body temperature methods, using intravascular measurements as the comparator. We excluded unpublished articles and commentaries. Furthermore, we excluded animal studies and articles that did not use the Bland–Altman approach to investigate accuracy of different body temperature measurement methods.

Outcome measures

The primary outcome was the assessment of accuracy and precision of non-invasive peripheral thermometers compared with intravascular methods.

Assessment of accuracy and precision

Accuracy was assessed by the Bland–Altman approach.[32] The mean difference (reference test minus index test) between measures is the bias. The 95% confidence interval (CI) of the differences between measures is the limits of agreement (LoA), a measure of the variance between body temperature measurements. Precision was assessed by the Lin concordance correlation coefficient.[33]

Study selection and data extraction

Two reviewers (SLC and DM) independently performed the initial search and the study selection by title, abstract and full text. All disagreements were managed through discussion. In the case of consensus not being reached, a third reviewer (NJG) was consulted.

Study design and setting, authors, study population, device, and body temperature measurements were independently extracted by four reviewers (SLC, EAO, DM and PA) using a standardised online spreadsheet (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia). One additional reviewer (EJS) checked all data abstractions.

Invasive extravascular measurement methods included urinary bladder, oesophageal, rectal, nasopharyngeal and tracheal body temperature-sensing probes. Non-invasive peripheral measurement methods included axillary, tympanic infrared, temporal scanner, oral, inguinal and zero heat flux (ZHF) thermometers. ZHF is a dot-shaped electronic thermometer that measures body temperature about 1–2 cm below the skin surface.

Statistical analysis

Continuous variables were pooled and reported as median (interquartile range [IQR]) or mean (standard deviation [SD]), as appropriate. Categorical variables were reported as frequencies and percentages. Pooled estimates of the mean bias between index and reference tests and the standard deviation of mean bias were synthesised using DerSimonian and Laird random effects meta-analyses.[34] Temperature-sensing intravascular catheters were considered the reference test for all pooled analyses, with data for each invasive or peripheral index test summarised separately. In this review, we will refer to temperature-sensing intravascular catheter as "PAC-derived", because of the paucity of data on other intravascular temperature-sensing probes. Pooled analyses were performed when at least three comparisons were available. The 95% CI for the mean bias and the SD were calculated using the appropriate equations.[35] The LoA between index and reference tests were calculated as the pooled mean bias ± 1.96 times the pooled SD.[32] It was decided a priori that the clinically acceptable mean bias was within ± 0.2°C and LoA within ± 0.5°C.[29,36]

Between-study heterogeneity was evaluated by the Cochran Q test and quantified by the I^2 statistic.[37] Heterogeneity was considered to be low, moderate or high at I^2 values of 25%, 50% and 75% respectively. High heterogeneity was investigated by sensitivity analyses and meta-regression. We performed a sensitivity analysis excluding studies that did not fully account for repeated measures within individual subjects. Moreover, we performed a further sensitivity analysis to explore the accuracy of electronic thermometers set in "core mode", which means adjusting temperatures measured at one peripheral site of the body (eg, ear canal) to estimate core temperature by manufacturer-made conversion algorithms that add automatically a fixed number to the temperature taken.[29] Meta-regression analyses were performed to investigate the impact of study-level characteristics on the mean bias, including year of publication, number of patients and measurements, patient age, proportion of male patients, illness severity score (Acute Physiological and Chronic Health Evaluation [APACHE] II or Simplified Acute Physiology Score [SAPS] 2), or the requirement for neuromuscular blockade, vasopressor, or mechanical ventilation.

Study quality was independently assessed by two reviewers (SLC and DM) using the QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies 2) tool[38] (Online Appendix, 4).

Publication bias was assessed using funnel plots and by Egger test. Data were analysed using Stata/SE14.0 (College Station, TX). A two-sided $P < 0.05$ was considered significant.

Results

Characteristics of included studies

We identified 601 unique citations (Figure 1), among which, 13 studies from 1991 to 2017[33,39-50] (632 patients; 105 375 measurements) were eligible for inclusion (Online Appendix, table S1).

The median number of patients was 42 (IQR, 21–60) per study and the median number of index-reference comparisons per study was 529 (IQR, 66–2000). The mean patient age was 64 years (SD, 7) and the percentage of male patients ranged from 47% to 86%. The percentage of mechanically ventilated patients ranged from 64% to 100% (n = 4), while the percentage of patients requiring vasopressor support ranged from 35% to 71% (n = 5). Three studies reported mean APACHE II scores that ranged from 15 to 25, while one study reported a mean SAPS 2 score of 43.4.

Intravascular measurements were performed by PAC (n = 12) or temperature-sensing catheters placed in the iliac artery (n = 1). The mean PAC-derived temperature ranged from 34.7°C to 37.7°C.

Accuracy and precision of non-invasive peripheral thermometers compared with PAC

Thirteen studies (632 patients) compared PAC with non-invasive peripheral thermometers (Figure 2). The results of the random effect meta-analysis are shown in Table1 and in the Online Appendix, figures S1 and S2. We did not find enough data to conduct a meta-analysis on the accuracy of cutaneous, oral thermometers and temporal scanner. None of the peripheral thermometers showed clinically acceptable mean bias and LoA.

A post hoc sensitivity analysis for studies comparing PAC with tympanic infrared set in core mode found a clinically acceptable mean bias (–0.02°C), but the LoA was still wide (–0.88 to 0.84°C).

We found an insufficient number of studies on precision of peripheral body temperature measurement methods to perform a meta-analysis.

Study heterogeneity was very high (99–100%). Study variability was partly explained by year of publication (coefficient 0.05; 95% CI, 0.01–0.09; P = 0.03) and mean variation in number of patients (coefficient 0.01; 95% CI, 0.00–0.02; P = 0.04).

Accuracy and precision of invasive extravascular thermometers compared with PAC

Seven studies (331 patients) compared PAC with invasive extravascular thermometers (Figure 3). The results of the random effect meta-analysis are shown in Table1 and in the Online Appendix, figures S3 and S4. All invasive extravascular thermometers showed clinically acceptable mean bias, although only oesophageal probes had LoA within the a priori set range. We did not find enough data to conduct a meta-analysis on endotracheal tube and nasopharyngeal body temperature sensing-probes.

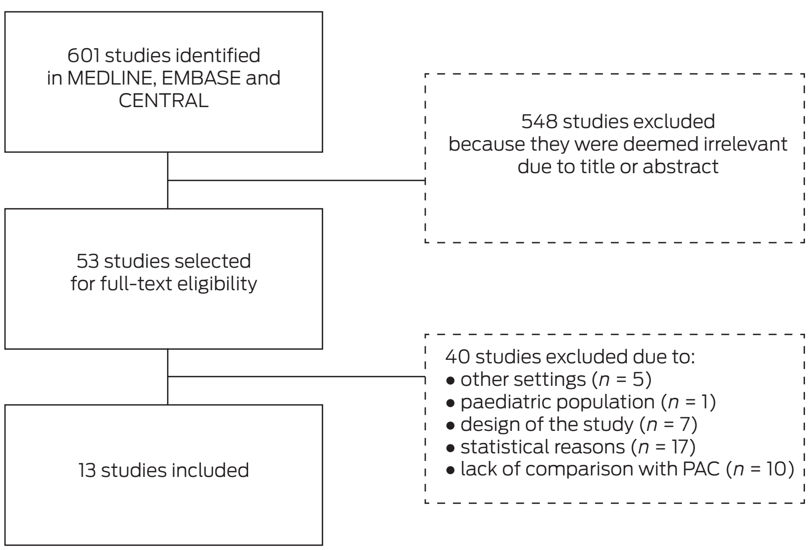
Study heterogeneity was very high (99–100%). Study variability was not explained by any year of publication or number of patients.

We found an insufficient number of studies on precision of invasive body temperature measurement methods to perform a meta-analysis.

Sensitivity analyses

When excluding studies that did not fully account for repeated measures within

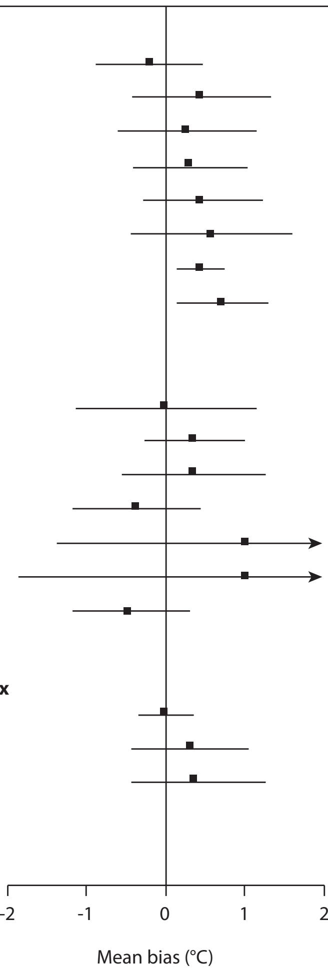
Figure 1. Flowchart of study selection



CENTRAL = Cochrane Central Register of Controlled Trials; PAC = pulmonary artery catheter.

Figure 2. Mean temperature difference between the pulmonary artery catheter and peripheral thermometers in 13 studies. Reported values include mean bias (index measurement subtracted from pulmonary artery catheter measurement) and precision (95% limits of agreement [LOA]). Smith* used a SolarTherm (RG Enterprises) axillary device; Smith† used an axillary DataTherm (Geratherm) device; Eshranghi‡ was measured at the forehead; Eshranghi§ was measured at the neck

Author	Year	N	Bias (95% LOA)
Axillary			
Farnell	2005	25	-0.20 (-0.84, 0.47)
Fulbrook	1997	60	0.46 (-0.42, 1.34)
Lefrant	2003	42	0.27 (-0.61, 1.15)
Moran	2007	110	0.29 (-0.42, 1.01)
Myny	2005	57	0.46 (-0.30, 1.22)
Nonose	2012	73	0.60 (-0.44, 1.64)
Smith*	2004	35	0.46 (0.15, 0.77)
Smith†	2004	35	0.72 (0.13, 1.31)
Tympanic			
Farnell	2005	25	0.00 (-1.16, 1.16)
Fulbrook	1997	60	0.37 (-0.26, 1.00)
Moran	2007	110	0.36 (-0.56, 1.28)
Nierman	1991	15	-0.38 (-1.20, 0.44)
Nonose	2012	73	1.03 (-1.38, 3.44)
Shin	2013	21	1.03 (-1.85, 3.91)
Stavem	1997	16	-0.45 (-1.19, 0.29)
Zero Heat Flux			
Dahyo-Fizelier	2017	54	0.00 (-0.35, 0.35)
Eshranghi‡	2014	103	0.32 (-0.42, 1.06)
Eshranghi§	2014	103	0.40 (-0.44, 1.24)



Publication bias

There was no funnel plot asymmetry in any of the analyses to support the presence of small study effects (Online Appendix, figures S6a and S6b).

individual subjects,[33,41,44,48,50] there were no qualitative differences in findings or heterogeneity (Online Appendix, table S2).

Quality assessment

The results of the QUADAS-2 evaluations are provided in the Online Appendix, table S3 and figure S5. The risk of bias for the index test was unclear, mostly because device calibration was not undertaken,[33,43-48,50] investigators skills in using index tests were not verified,[39,40,43,44,46,48,50] and there was no control for possible confounders[33,39-41,43-46,49,50] (Online Appendix, table S4).

Discussion

Main findings

This systematic review and meta-analysis investigated the accuracy of non-invasive peripheral body temperature measurement methods in ICU patients, most of whom were mechanically ventilated and/or haemodynamically unstable. Core temperature ranged from moderate hypothermia to just above normothermia. We found that none of the non-invasive peripheral thermometers had clinically acceptable mean bias and LoA. Moreover, all provided a variable underestimation of core temperature. When tympanic infrared thermometers were set in "core mode", the mean bias decreased ten-fold and became clinically acceptable, but the LoA remained wide. We found an insufficient number of studies on oral, skin surface, and temporal scanner to perform a meta-analysis on the accuracy of such methods.

Among invasive extravascular methods, only temperature-sensing oesophageal probes were clinically acceptable. Study heterogeneity was high and the risk of bias was unclear. We did not find enough studies to assess accuracy of endotracheal tube and nasopharyngeal body temperature-sensing probes. Finally, we found an insufficient number of studies on precision to perform a meta-analysis.

Relationship with previous studies

To date, no study has conducted a systematic review and meta-analysis of the accuracy of body temperature measurement methods in ICU patients. In 2006, Hooper and Andrews[51] conducted a systematic review of 23 articles on the accuracy of peripheral thermometers in a mixed population of acutely ill hospitalised adults. The authors concluded that only oral measurements were accurate in estimating core body temperature, although high study heterogeneity warranted further investigation. Because of

Table1. DerSimonian and Laird random effects meta-analysis of 13 studies reporting the mean temperature difference between thermometer measurements in critically ill patients. Reported values include pooled mean bias (mean index measurement subtracted from mean pulmonary artery catheter [PAC] measurement), pooled standard deviation, and pooled 95% limits of agreement

Body temperature measurement methods	Comparisons (*n*)	Studies (*n*)	Pooled mean bias		Pooled SD		Pooled 95% limits of agreement
			95% CI	I^2	95% CI	I^2	
PAC							
Urinary bladder	5	5	−0.06 (−0.16 to 0.05)		0.38 (0.15–0.62)	100%	−0.80 to 0.68
Oesophagus	3	3	0.06 (−0.07 to 0.18)		0.23 (0.10–0.36)	99%	−0.39 to 0.51
Rectum	3	3	−0.05 (−0.21 to 0.10)		0.78 (0.06–1.50)	99%	−1.58 to 1.48
Axillary	9	7	0.36 (0.21–0.50)	99%	0.38 (0.32–0.45)	97%	−0.38 to 1.10
Tympanic	7	7	0.28 (−0.07 to 0.63)	99%	0.70 (0.37–1.03)	100%	−1.09 to 1.65
Zero heat flux	3	2	0.24 (0.04–0.44)	100%	0.33 (0.20–0.46)	100%	−0.41 to 0.89

SD = standard deviation.

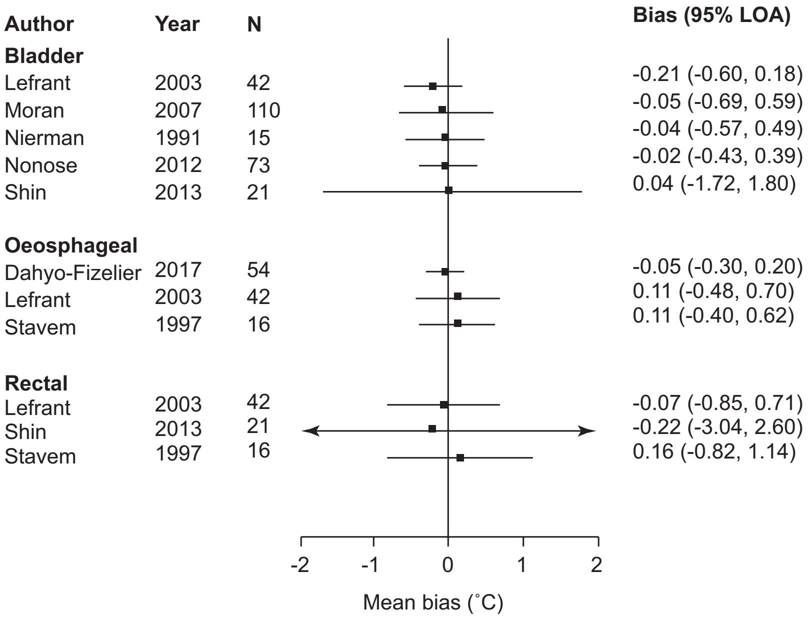
differences in inclusion criteria (not conducted in an ICU setting, not only involving adult patients, or not assessing accuracy with the Bland–Altman approach), most of these studies were not included in our review.

In 2011, Jefferies and colleagues[29] completed a review of three articles on the accuracy of peripheral thermometry in estimating core temperature among febrile ICU patients. The authors concluded that both tympanic and oral thermometry provide an accurate measure of core temperatures within the febrile range. However, this study was underpowered to provide a pooled estimation of accuracy and did not evaluate the degree of heterogeneity among such articles. These factors significantly limit the applicability of the above findings. In a 2015 study, Niven and colleagues[28] reviewed the accuracy of peripheral thermometers compared with invasive thermometers and pooled the results of 75 studies on children and adults. All invasive devices carried clinically acceptable mean bias and LoA compared with the PAC. However, the authors found that peripheral thermometers did not have clinically acceptable accuracy and discouraged their clinical use. Unfortunately, this systematic review and meta-analysis may be biased by studies from different clinical settings (45% ICU, 27% general ward/mixed, 16% emergency department, 7% operating theatre, 4% outpatient clinic). Specifically, physiological and iatrogenic conditions of critical illness (eg, fluid shifts, haemodynamic instability, nasogastric feeding, and parenteral infusions) may create local and rapid systemic temperature alterations, which make body temperature in each anatomical district different from those seen in non-ICU patients.[23,52] Moreover, recent evidence identified skin-surface axillary temperature probes as main factors involved in the transmission of *Candida auris* infection,[53] raising additional concerns on their use in the ICU.

Implications

The lack of accuracy of peripheral thermometers in estimating core temperature implies the need to limit the use of such methods in severe ICU patients due to the risk of obtaining misleading clinical information. Moreover, our study implies that, among invasive body temperature measurement methods, only oesophageal probes have acceptable accuracy and should, therefore, be preferred in clinical practice. Finally, the lack of evidence on precision among all measurement techniques as well as the low accuracy of several peripheral and even invasive extravascular body temperature methods are of great concern. This is particularly relevant to trials focusing on temperature control in patients after cardiac arrest[8-10,12] or after traumatic brain injury[11,13,14] or convulsive status epilepticus[54] or patients with infection,[15-17] where core

Figure 3. Mean temperature difference between the pulmonary artery catheter and central thermometer measurements in seven studies. Reported values include mean bias (index measurement subtracted from pulmonary artery catheter measurement) and precision (95% limits of agreement [LoA])



temperature was estimated by many different extravascular invasive methods (Online Appendix, 4). Furthermore, the axillary route was considered the standard method for measuring body temperature in the REACTOR trial,[17] which evaluated acetaminophen safety for fever control in ICU patients. Our study highlights that, in most of these trials, the technology of body temperature measurement was likely flawed.

Strengths and limitations

To our knowledge, we are the first to perform a comprehensive systematic review and meta-analysis of daily used body temperature monitoring tools in ICU patients. In addition, we shed light on the major shortcomings of peripheral thermometers in clinical practice. Finally, we provide strong evidence to inform the research agenda in this field, specifically when temperature management is intended to be an intervention that modifies patient-centred outcomes in specific clinical conditions, such as cardiac arrest, traumatic brain injury, and sepsis.

However, we acknowledge some limitations. We restricted our research to articles that evaluated the accuracy of peripheral thermometers using the Bland–Altman approach. Although many statistical methods have been used in this kind of research[33] and their inclusion might add information on other body temperature measurement tools (eg, oral or temporal scanner), we selected such a statistical approach because of its wide acceptance and to provide homogeneity to the data interpretation. Furthermore, we did not contact the authors of each study to obtain original data and perform a patient-level meta-analysis. Nevertheless, the observational nature of the articles included and the unclear control for possible confounders would have limited the additional value of such analysis. Moreover, we acknowledge the validity that LoA calculated as the pooled mean bias ± 1.96 times the pooled SD increases with larger sample sizes. However, this is the standard method to calculate LoA and there is no specific threshold of sample size below which it is invalid. Finally, we did not investigate the accuracy of body temperature measurement methods in the setting of marked hypothermia or fever, but this assessment had been previously attempted and found to be difficult due to the small number of studies.[29]

Conclusion

In our systematic review and meta-analysis, peripheral thermometers showed a clinically unacceptably low degree of accuracy compared with PAC. In contrast, oesophageal measurements showed clinically acceptable accuracy in ICU patients, suggesting that their use may be justified. However, in most of the trials of temperature management in clinical conditions in which its accurate measurement matters, the technology of body temperature measurement was flawed. Finally, the lack of data for most thermometer types and the low quality of the evidence available remain a major problem.

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Competing interests

None declared.

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