Accuracy of Zero-Heat-Flux Cutaneous Temperature in Intensive Care Adults

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Objectives: To compare accuracy of a continuous noninvasive cutaneous temperature using zero-heat-flux method to esophageal temperature and arterial temperature.

Design: Prospective study.

Setting: ICU and NeuroICU, University Hospital.

Patients: Fifty-two ICU patients over a 4-month period who required continuous temperature monitoring were included in the study, after informed consent.

Interventions: All patients had esophageal temperature probe and a noninvasive cutaneous device to monitor their core temperature continuously. In seven patients who required cardiac output monitoring, continuous iliac arterial temperature was collected. Simultaneous core temperatures were recorded from 1 to 5 days. Comparison to the esophageal temperature, considered as the reference in this study, used the Bland and Altman method with adjustment for multiple measurements per patient.

Measurements and Main Results: The esophageal temperature ranged from 33°C to 39.7°C, 61,298 pairs of temperature using zero-heat-flux and esophageal temperature were collected and 1,850 triple of temperature using zero-heat-flux, esophageal temperature, and arterial temperature. Bias and limits of agreement for temperature using zero-heat-flux were 0.19°C ± 0.53°C compared with esophageal temperature with an absolute difference of temperature pairs equal to or lower than 0.5°C of 92.6% (95% CI, 91.9–93.4%) of cases and equal to or lower than 1°C for 99.9% (95% CI, 99.7–100.0%) of cases. Compared with arterial temperature, bias and limits of agreement were −0.00°C ± 0.36°C with an absolute difference of temperature pairs equal to or lower than 0.5°C of 99.8% (95% CI, 95.3–100%) of cases. All absolute difference of temperature pairs between temperature using zero-heat-flux and arterial temperature and between arterial temperature and esophageal temperature were equal to or lower than 1°C. No local or systemic serious complication was observed.

Conclusions: These results suggest a comparable reliability of the cutaneous sensor using the zero-heat-flux method compared with esophageal or iliac arterial temperatures measurements. (*Crit Care Med* 2017; 45:e715–e717)

Key Words: core temperature; esophageal temperature; intensive care; surface temperature; zero-heat-flux method

Temperature is one of the vital signs usually monitored in patients of ICUs. Indeed, fever occurs frequently in ICU and may require targeted temperature management (TTM). In a large retrospective study, fever (body temperature ≥ 38.3°C) occurred in 44% of ICU patients, and values over 39.5°C are associated with increased risk of mortality (1). By contrast, TTM improves outcomes in cardiac arrest (2–4), in hypoxic ischemic encephalopathy in neonatal patients (5, 6) and in controlling refractory intracranial hypertension in brain injury (7). Thus, accuracy of temperature assessment is essential (7).

Peripheral and core temperature assessment are available, but in ICU patients, core temperature is preferred to reflect vital organs temperature and to avoid external factors such as peripheral vasoconstriction. The "gold standard" is the pulmonary arterial catheter, but esophageal, bladder, or rectal probes are being mostly used in practice with relative good accuracy, with for all, own adverse events. They remain recommended in ICU because noninvasive methods showed lower accuracy (8).

The zero-heat-flux (ZHF), a noninvasive method, of deep body temperature measurement from the skin surface has been

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This work was performed in ICU and NeuroICU of the University Hospital of Poitiers.

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developed several decades ago (9). Recently, a new sensor, the 3M SpotOn (3M, St Paul, MN), placed on skin surface of the forehead of surgical patients, was studied to measure continuously the core temperature. Up to date, no study evaluated the marketed version in ICU patients (10).

As esophageal temperature monitoring is widely spread in ICU patients, we compared temperatures from the ZHF method and esophageal probe. To take into account potential inaccuracy of esophageal temperature monitoring, we compared both temperatures to femoral arterial ones' in a subgroup of patients with invasive hemodynamic monitoring.

After ethic committee approval, 52 surgical ICU patients of the University hospital of Poitiers were included in the study over 4 months (demographic data in **Supplemental Table 1**, Supplemental Digital Content 1, http://links.lww.com/CCM/C343). Patients were enrolled within the first 48 hours after admission and data from esophageal probe (T_{eso}), ZHF sensor (T_{ZHF}), and femoral arterial catheter if available (T_{art}) were recorded automatically at a 5-minute interval for an average of 4 days (method in **supplemental data**, Supplemental Digital Content 2, http://links.lww.com/CCM/C344). Agreement between T_{eso} (reference) and T_{ZHF} was assessed with calculation of bias and limits of agreement (LA) adjusted (11). In seven patients, T_{art} was available; T_{eso} and T_{ZHF} were compared with T_{art} (considered as the reference). Percentage of the absolute difference of temperature pairs between reference and tested methods equal to or lower than 0.5°C and 1°C were also described. The difference in consecutive temperature values of T_{eso} and T_{ZHF} was assessed by linear regression and R^2 estimation.

A total of 61,298 pairs of T_{ZHF} and T_{eso} were collected, ranged from 33.0°C to 39.7°C (**Table 1**). Compared with T_{eso}, bias and LA for T_{ZHF} were –0.19°C ± 0.53°C (**Fig. 1**). The absolute difference of temperature pairs was equal to or lower than 0.5°C for 92.6% (95% CI, 91.9–93.4%) of cases and equal to or lower than 1°C for 99.9% (95% CI, 99.7–100.0%) of cases (Table 1). We observed a significant correlation between two consecutive measures of temperature with T_{ZHF} or T_{eso} ($R^2 = 0.45$; $p < 0.001$) (**Supplemental Fig. 1**, Supplemental Digital Content 3, http://links.lww.com/CCM/C345; legend, Supplement Digital Content 2, http://links.lww.com/CCM/C344) and no significant difference between individual results of the first paired temperatures ($p = 0.85$) (**Supplemental Table 2**, Supplemental Digital Content 4, http://links.lww.com/CCM/C346) with bias and LA of –0.05 ± 0.55.

A total of 1,850 triplets of T_{art}, T_{ZHF}, and T_{eso} were collected. Compared with T_{art}, bias and LA were 0.00°C ± 0.36°C and –0.05°C ± 0.25°C for T_{ZHF} and T_{eso}, respectively (**Supplemental Fig. 2**, Supplemental Digital Content 5, http://links.lww.com/CCM/C347; legend, Supplement Digital Content 2, http://links.lww.com/CCM/C344). The absolute difference of temperature pairs was equal to or lower than 0.5°C for 99.8% (95% CI, 95.3–100%) of cases between T_{art} and T_{ZHF} and for 99.8% (95% CI, 95.3–100%) of cases between T_{art} and T_{eso} (Table 1). Bias and LA were constant from 33°C to 39.7°C (**Supplemental Fig. 3**, Supplemental Digital Content 6, http://links.lww.com/CCM/C348; legend, Supplemental Digital Content 2, http://links.lww.com/CCM/C344).

The current study is the first one to compare the core temperature obtained by a noninvasive ZHF method with two invasive ones, esophageal and iliac arterial temperature methods, in ICU patients. The cutaneous sensor provided an accurate estimation of esophageal temperature, the reference, with a bias and LA of –0.19°C ± 0.53°C. In 92.6% of cases, the absolute differences of temperature pairs were equal to or lower than 0.5°C; for the remaining observations, no clinical variable was identified to explain higher absolute difference. Importantly for clinical practice, bias and precision of T_{ZHF} remained stable over the range of temperatures recorded, from 33.0°C to 39.7°C. When iliac arterial temperature was considered as the reference method, bias and LA and absolute difference of temperature pairs, for esophageal and ZHF methods, were similar.

Up to date, few articles explored accuracy of ZHF method compared with invasive ones in different populations and reports results slightly comparable to ours (10, 12–14). Pulmonary arterial temperature (T_{PA}) is still the "gold standard" for core temperature, but we chose esophageal temperature as the reference method because of its largely widespread within the recommended methods in ICUs (8). Interestingly, T_{eso} was reported to be reliable to T_{PA} in ICU patients with comparable results than ours by comparing T_{eso} and T_{art} (15, 16). Furthermore, in our study, 99.8% of absolute differences between T_{ZHF} and T_{art} were equal to or lower than 0.5°C. In clinical practice, it is admitted that a SD ranged from 0.3°C to 0.5°C is reliable, meaning LA ranged from 0.6°C to 1°C (16, 17). Thus, according to our results, ZHF method is more accurate than other noninvasive methods and comparable to invasive ones' (15, 18). No major side effect was noticed during this study and the downside to its use could be the cost. One of the limits of this study is that majority of patients were brain-injured patients and results must be confirmed in other populations of ICU patients as primarily septic or postoperative patients.

TABLE 1. Bias, Limits of Agreement, and Absolute Differences of Temperature Pairs for the Different Temperature Techniques

Assessments Temperature Techniques	No. of Pairs	Bias (SD)	Limits of Agreement	Absolute Difference of Temperature Pairs ≤ 0.5°C (% [95% CI])	Absolute Difference of Temperature Pairs ≤ 1°C (% [95% CI])
Esophageal surface	61,298	−0.19 (0.27)	−0.72 to 0.34	92.6 (91.9–93.4)	99.9 (99.7–100.0)
Arterial surface	1,850	−0.00 (0.18)	−0.36 to 0.36	99.8 (95.3–100.0)	100
Arterial esophageal	1,850	−0.05 (0.13)	−0.30 to 0.20	99.8 (95.3–100.0)	100

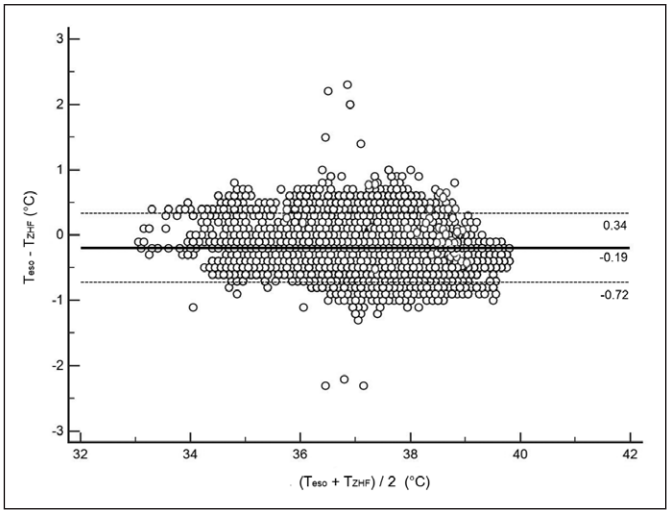

Figure 1. Bland-Altman plots of temperatures obtained concomitantly with esophageal probe (T_{eso}) and zero-heat-flux (ZHF) sensor (T_{ZHF}). *Solid line* represents the bias between the two methods of temperature assessment, and *short-dashed lines* represent the 95% limits of agreement. Limits of agreement are adjusted for repeated measures from the same subject.

To conclude, in our study, the core temperature monitored by the ZHF method is reliable compared with esophageal and arterial temperature and its accuracy is stable over a large range of temperature. This sensor is the first to provide a noninvasive continuous monitoring of core temperature. Our results have to be confirmed in other population of ICU patients.

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