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Accuracy and Precision of Noninvasive Temperature Measurement in Adult Intensive Care Patients

By Lari Lawson, RN, MN, Elizabeth J. Bridges, RN, PhD, CCNS, Isabelle Ballou, RN, BSN, Ruthe Eraker, RN, BSN, Sheryl Greco, RN, MN, CCRN, Janie Shively, RN, BSN, and Vanessa Sochulak, RN, BSN

Background Research on the accuracy and precision of noninvasive methods of measuring body temperature is equivocal.
Objectives To determine accuracy and precision of oral, ear-based, temporal artery, and axillary temperature measurements compared with pulmonary artery temperature.
Methods Repeated-measures design conducted for 6 months. Sequential temperature measurements on the same side of the body were obtained within 1 minute, with measurements repeated 3 times at 20-minute intervals. Accuracy, precision, and confidence limits were analyzed.
Results In 60 adults with cardiopulmonary disease and a pulmonary artery catheter, mean pulmonary artery temperature was 37.1°C (SD 0.6°C, range 35.3°C-39.4°C). Mean (SD) offset from pulmonary artery temperature (with the mean reflecting accuracy and SD reflecting precision) and confidence limits were 0.09°C (0.43°C) and -0.75°C to 0.93°C for oral measurements, -0.36°C (0.56°C) and -1.46°C to 0.74°C for ear measurements, -0.02°C (0.47°C) and -0.92°C to 0.88°C for temporal artery measurements, and 0.23°C (0.44°C) and -0.64°C to 1.12°C for axillary measurements. Percentage of pairs with differences greater than ±0.5°C was 19% for oral, 49% for ear, 20% for temporal artery, and 27% for axillary measurements. Intubation increased oral measurements compared with pulmonary artery temperatures (mean difference 0.3°C, SD 0.3°C, $P = .001$).
Conclusions Oral and temporal artery measurements were most accurate and precise. Axillary measurements underestimated pulmonary artery temperature. Ear measurements were least accurate and precise. Intubation affected the accuracy of oral measurements; diaphoresis and airflow across the face may affect temporal artery measurements. (*American Journal of Critical Care.* 2007;16:485-496)

Temperature monitoring in critical care provides important data required to guide delivery of care. However, measurement of core body temperature requires the placement of a pulmonary artery catheter. Alternatives include invasive temperature monitoring (esophageal, bladder, rectal) or noninvasive methods (oral, ear-based, temporal artery, or axillary). Clinicians are challenged to select the measurement method that is most appropriate for a patient and provides the most accurate and precise approximation of core temperature. The purpose of this study was to describe the accuracy and precision of 4 noninvasive methods (oral, ear-based, temporal artery, and axillary) compared with core (pulmonary artery) temperature in adult patients in the intensive care unit (ICU).

Noninvasive Methods of Temperature Measurement

Oral

Oral temperature measurement is a standard in healthcare settings. Factors that may affect oral temperature include the ingestion of hot or cold liquids, smoking, tachypnea, and gum chewing. Administration of oxygen up to 6 L/min and open- and closed-mouth breathing do not affect oral temperature measurements.[1,2] Oxygen administered via a face mask has a statistically but not clinically significant effect (<0.3°C decrease) on oral temperature measurements.[3-5] Despite the administration of warmed gases through an endotracheal tube, the presence of the endotracheal tube does not cause clinically significant differences in oral temperature measurements compared with core temperature.[1,6-8]

Oral temperatures are not affected by open- or closed-mouth breathing or oxygen flow up to 6 L/min.

Ear-Based (Infrared Tympanic Temperatures)

Ear-based temperature is measured in the ear canal, which radiates infrared energy in proportion to its temperature. A noncontact infrared thermometer is used to detect the energy emitted from the ear canal and tympanic membrane.[9] The ease and speed of use are considered benefits of ear-based measurements; however, incorrect technique may affect the accuracy and reliability of the measurements.

In a study by Erickson and Kirklin,[10] who used 344 sets of triplicate readings, the repeatability of ear-based temperature measurements was ±0.2°C. In another study,[11] the following errors in technique were observed: failure to inspect lens (99.6%), reaching/using opposite ear (9%), and improper seal (2%). These errors in measurement technique may contribute up to 25% of the variability in measurements.[12] In addition, ear-based temperatures are more variable than are oral temperatures. In a study by Giuliano et al,[12] oral temperature measurements underestimated pulmonary artery temperature (mean -0.15°C, SD 0.36°C). Although the tympanic thermometer had an accuracy similar to that of the oral thermometer, the standard deviation indicated increased variability (mean -0.11°C, SD 0.57°C).

Two recent studies[13,14] showed similar results regarding the higher variability of ear-based temperature measurements. In a study[13] of 25 ICU patients, the ear-based measurement was a mean of 0.0°C (SD 0.59°C, range -2.3°C to 1.0°C) different from pulmonary artery temperature, and the 95% limits of agreement were from -1.2°C to 1.2°C. In another study[14] of critically ill patients in which the accuracies of tympanic, axillary, and urinary bladder temperatures were determined relative to pulmonary artery temperature, the bias (limits of agreement) for each site was 0.36°C (-0.56°C, 1.28°C) for tympanic, -0.05°C (-0.69°C, 0.59°C) for axillary, and 0.30°C (-0.42°C, 1.01°C) for bladder.

Temporal Artery Temperatures

Measurement of temperature over the temporal artery is a noninvasive method that does not require contact with mucous membranes. The temporal

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artery is not significantly affected by thermoregulatory changes; therefore, perfusion should be stable in most conditions.[15] Because of the high perfusion rate of this artery, its temperature also may be an accurate indicator of core temperature.[16] The temperature of the skin directly over the superficial temporal artery (forehead) does not represent the body's core temperature because of heat loss through the skin (radiant heat loss). A technique known as the arterial heat balance method is used to correct for this radiant heat loss. With this method, the temporal artery thermometer measures ambient temperature at the same time as it measures the absolute temperature of the skin surface over the artery.[17]

Diaphoresis can affect the accuracy of measurements of temporal artery temperature. In order to control for this factor, while the temporal artery temperature is being obtained the SCAN button remains depressed and an additional temperature measurement is taken directly behind the ear. In a normothermic patient, the skin is relatively vasoconstricted and cool, so this additional temperature measurement is ignored. By contrast, in a diaphoretic patient, the temperature behind the ear will not be as affected by perspiration, thereby providing a more accurate temperature measurement.[17] The thermometer then computes arterial temperature by restoring the measured heat loss to the absolute peak surface temperature measurement. In a study by Carroll et al,[18] the temporal artery measurements obtained from the forehead only were significantly lower than pulmonary artery temperatures (mean difference from pulmonary artery temperature 1.54°C, SD 1.3°C, $P < .001$). In contrast, measurements of temporal artery temperature obtained by using the combined forehead and behind-the-ear method were more accurate and precise (mean difference 0.16°C, SD 1.1°C, $P = .17$) compared with pulmonary artery temperature, suggesting the effects of diaphoresis on the measurements. For the current study, the forehead plus behind-the-ear method was used for all patients. During each sequence, the thermometer measures the temperature of the skin and the ambient temperature at approximately 1000 measurements per second. The thermometer also solves the heat balance equation multiple times per second, selects the highest of the readings, and discards all other readings. The final temperature displayed is the solution to the proprietary algorithm, which gives the maximum temperature reading during a particular episode.

Only 4 studies[16,18-20] have been done in adult patients to evaluate the accuracy and precision of temporal artery measurements versus pulmonary artery temperature measurements. In a study[18] of 300 patients after cardiac surgery or patients with a cardiac diagnosis requiring pulmonary artery catheterization, the temporal artery temperature measurement (thermometer from Exergen Corp, Watertown, Massachusetts) was significantly higher than the pulmonary artery temperature measurement when only the forehead value was used (mean difference -1.03°C, SD 1.18°C, $P < .001$). When the forehead and behind-the-ear measurements were used, no significant difference was found (mean difference from pulmonary artery measurement 0.16°C, SD 1.1°C, $P = .17$).[18] In a study[19] of 57 critically ill patients (32 in the medical ICU, 25 in the surgical ICU), no significant difference was found between the pulmonary artery and temporal artery measurements (mean difference 0.14°C, SD 0.51°C, 95% confidence interval 0.04°C-0.23°C). In an intraoperative study[16] of 41 patients (American Society of Anesthesiologists class 1 and 2), the accuracy and precision of "deep forehead" temperature (thermometer from Coretemp, Terumo, Tokyo, Japan) compared with pulmonary artery temperature were 0.0°C and 0.3°C, respectively.

In a study[20] of 56 patients after cardiac surgery (30 adults, aged 36-83 years; 26 children, aged 9 days to 13 years) in which the SensorTouch (Phillips, Inc, Rotterdam, the Netherlands) was used, the mean difference between pulmonary artery and temporal artery measurements was 1.3°C (SD 0.6°C), with 89% of the temperatures differing by more than 0.5°C. It is unclear why the temperature measurements differed by such a large amount, although limitations of the study were a lack of information on the calibration of the thermometers[21] and the time between each measurement in the triplicate set.

The presence of a face mask for oxygen delivery or an endotracheal tube has no clinically significant effect on oral temperature.

Axillary Temperatures

Axillary temperature is a skin temperature for an area that is somewhat protected from the ambient air. The axillary temperature consistently varies from the core (pulmonary artery) temperature. For example, in a study[10] of 38 critically ill cardiovascular patients, the axillary temperature was lower than pulmonary artery temperature by a mean of 0.68°C (SD 0.57°C). In another study[22] of 42 critically ill patients with sepsis, the axillary temperature was higher than the pulmonary artery temperature by a mean of 0.27°C (SD 0.45°C). The difference in results may reflect different populations of patients. In patients after cardiac surgery, thermoregulatory vasoconstriction may result in decreased axillary temperature. In patients with sepsis, peripheral vasodilatation may increase the axillary temperature.

Methods

A repeated-measures design was used to describe the accuracy and precision of 4 noninvasive temperature measurements (oral, ear-based, temporal artery, and axillary) compared with pulmonary artery temperature. Study participants served as their own controls. The study was approved by the institutional review board at the University of Washington and carried out in accordance with the ethical standards set forth in the Helsinki Declaration of 1975. Consent was provided by each patient or the patient's legal representative. The thermometers were loaned by the companies for research purposes and were returned to the companies after use.

Sample

During a 6-month period, a convenience sample (n = 60) of adult ICU patients at the University of Washington Medical Centers, Seattle, Washington, an academic medical center, were studied. Patients who had a pulmonary artery catheter in place because of clinical necessity participated in the study. Patients were excluded if they had an oral abscess, stomatitis, oral trauma, or head trauma, or if their tympanic membrane was not intact or could not be visualized by otoscopy.

Because of the high perfusion in the temporal artery, measurements of temperature there can reflect core temperatures.

Temperature Measurement

The 4 external temperature measurements and the pulmonary artery temperature (a total of 5 measurements) were obtained in a random order within a 1-minute period. The temperatures were measured at each site on the same side of the body and only if the site was fully exposed. The measurements, which were manually recorded from each thermometer, were repeated every 20 minutes for 3 measurement sequences (a total 15 measurements, 3 per site).

The 6 study investigators (all experienced ICU nurses) were trained to perform the procedures for each temperature measurement as described in the next section.

Intrarater reliability was established; each investigator performed each measurement as described in the methods section until she achieved repeated temperature measurements for a given site that were within 0.1°C. Similarly, interrater reliability was defined as having 2 investigators obtain measurements of temperatures from a specified site that were within 0.1°C. A refresher was performed monthly throughout the experiment to ensure reliability of performance.

Pulmonary Artery Temperature. Each patient had a pulmonary artery catheter (VIP Swan-Ganz catheter, Edwards Lifesciences, Irvine, California) in place for a medical reason unrelated to this study. The correct position of the catheter was checked by assessing the most current chest radiograph and waveforms indicating correct positioning in the pulmonary artery.

Oral Temperature. The oral temperature was obtained by using the SureTemp Plus Electronic Thermometer Model 692 (Welch Allyn, Skaneateles Falls, New York). The thermometer has a temperature range of 26.6°C to 43.3°C, with an accuracy of ±0.1°C. The probe, which was placed in the posterior sublingual pocket, was held by the investigator during the temperature measurement to maintain contact between the probe tip and the tissue. Patients who were tachypneic or mouth breathers were encouraged to form the best seal possible around the thermometer. A note regarding each patient's ability to make an adequate seal was made on the study record. Nasal cannulas or face masks for oxygen delivery were left in place. Patients who were intubated also were included in the study. The probe was positioned to avoid contact with the endotracheal tube by placing it on the side opposite the endotracheal tube.[1,6] No attempt was made to close a patient's mouth around the probe if the patient was unable to spontaneously accomplish this action.[6]

Ear-Based Temperature. The ear-based measurement was obtained by using the Genius Infrared Tympanic Thermometer 3000A (Sherwood Medical, St Louis, Missouri). The thermometer has a temperature range of 29.4°C to 43.3°C, with an accuracy of ±0.1°C. Before the start of the study, each patient's ear canal was inspected with an otoscope to ensure that the tympanic membrane could be visualized. After otoscopic inspection, a 2-minute delay was observed to minimize the cooling effects of the otoscope on the ear canal (temperature drawdown). Temperature measurements were obtained in the following manner: After the probe tip was inspected to ensure that it was free of dirt or debris, a cover was placed over the probe. The thermometer was set in the tympanic mode with the site adjustment set to CORE. The probe tip was inserted into the ear canal without an ear tug. The probe tip was then seated in the ear canal by rotating the handle a quarter turn toward the jaw. If a repeat temperature measurement was needed, a 2-minute period was observed to control for drawdown. All measurements were obtained in the same ear. If a patient was lying on his or her side, the nondependent ear was used.

Temporal Temperature. The temporal temperature was measured by using the Exergen TemporalScanner Temporal Artery Thermometer (Exergen Corp, Watertown, Massachusetts). This thermometer has a reported accuracy of ±0.1°C. The temperature measurement was obtained by sliding the thermometer probe midline straight across the forehead (Figure 1). In an effort to control for the effects of perspiration on the temporal artery measurement, an additional temperature measurement behind the earlobe was obtained (continuation of the temporal measurement). If a patient was in a lateral position, the temperature was measured on the "up" (nondependent) side of the forehead.

A crucial factor in the accuracy of the temporal artery thermometer was keeping the thermometer's infrared lens clean to avoid any interference from buildup of skin oil. In a study of 300 adults by Carroll et al,[18] the rate of measurement error of the temporal artery temperature versus the pulmonary artery temperature due to not cleaning the lens was -0.11°C/month. In our study, the thermometer was cleaned daily and whenever any soiling of the lens occurred. In addition, to avoid temperature drawdown, a minimum 30-second delay was used if a measurement had to be repeated.

Axillary Temperature. Axillary temperature was measured with the same thermometer used for oral temperature measurements: the SureTemp Plus Electronic Thermometer Model 692 (Welch Allyn). The thermometer was placed in the "axillary" mode. (Specifications for this thermometer were provided in the section on oral temperature.) The temperature probe requires direct contact with the skin, although no shaving or clipping of hair was required. Temperature measurements were obtained in the following manner: With the axillary mode indicator flashing, the patient's arm was lifted so that the entire axilla was easily seen. The probe was placed as high as possible in the axilla. The probe tip did not come into contact with the patient until the probe was placed in the measurement site. Verification that the probe tip was completely surrounded by axillary tissue was accomplished, after which the patient's arm was placed snugly at the patient's side. The patient's arm was held in this position to avoid movement of the arm or the probe during the measurement cycle.

Other Factors. Published reports suggest that several other factors may affect the accuracy of temperature measurements. The ingestion of hot or cold liquids affects oral temperature measurements for up to 7 minutes but has no effect on tympanic measurements.[23] To control for this effect, we did not obtain temperature measurements for at least 15 minutes after a patient had ingested either hot or cold liquids. Ambient temperature was measured by using a calibrated wet bulb globe thermometer positioned within 3 ft (0.9 m) of the patient's head and away from a direct light source.

Equipment Calibration. The clinical engineering department at the medical center calibrated all noninvasive thermometers before the start of the study, monthly during data collection, and upon completion of the study. The calibration was done in accordance with manufacturers' recommendations. The thermometers were considered calibrated if they were within 0.2°C of the standard. A thermometer was recalibrated if it was more than 0.2°C different from the standard. Calibration of the pulmonary artery catheter thermistor was verified after catheter removal against a certified thermometer with accuracy

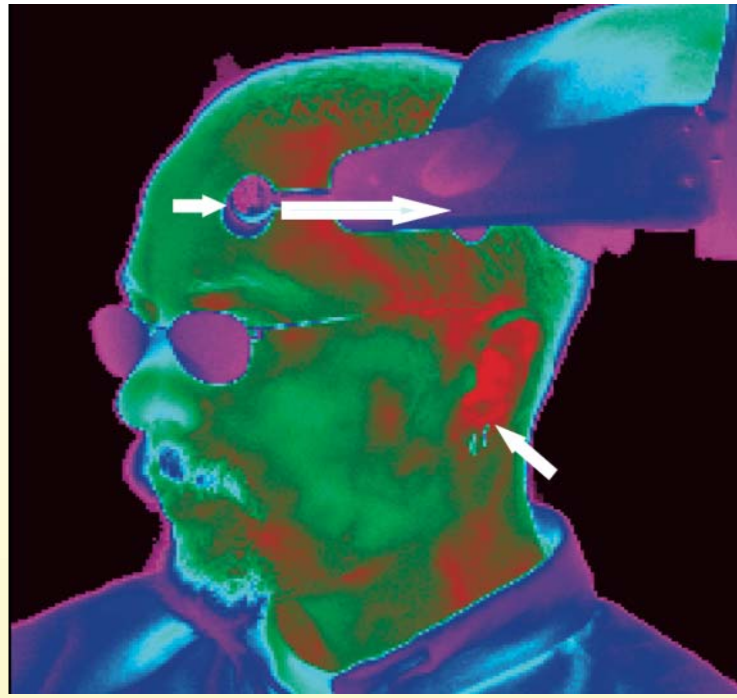

Figure 1 High-resolution infrared image of a person's temporal artery being scanned with the TAT-5000 Temporal Artery Thermometer. The measurement is obtained by swiping the thermometer probe across the forehead and behind the ear.

Courtesy Exergen Corporation, Watertown, Massachusetts.

Oral temperatures are slightly lower and temporal artery temperatures are slightly higher than pulmonary artery temperatures, but ear-based measurements are the least accurate and precise.

Table 1
Demographics

Characteristic	Value
Sex, No. of patients	
Male	40
Female	20
Age, mean (SD), y	57 (15)
Diagnosis, No. of patients	
Cardiac medicine	28
Cardiac surgery	20
Pulmonary medicine	6
Pulmonary surgery	6
Other medicine	3
Core temperature, °C	
Mean (SD)	37.1 (0.6)
Range	35.3-39.4
Mode of oxygen delivery, No. of patients	
Mechanical ventilation/endotracheal tube	13
Nasal cannula	24
No supplemental oxygen	23
Vasopressors, mean (SD)	
Dopamine, μg/kg per minute (n = 7)	2.4 (0.9)
Epinephrine, μg/kg per minute (n = 3)	0.02 (0.1)
Norepinephrine, μg/kg per minute (n = 3)	0.08 (0.5)
Vasopressin, U/min (n = 3)	0.06 (0.02)
Ambient temperature, mean (SD), °C	18.8 (1.2)

Table 2
Temperature data[a] (N = 60)

	Temperature, °C			
Site	Mean (SD)	Minimum	Maximum	Median
Pulmonary artery	37.1 (0.6)	35.3	39.4	37.0
Oral	37.0 (0.5)	36.3	39.5	36.9
Ear-based	37.4 (0.8)	35.3	39.9	37.4
Temporal artery	37.1 (0.6)	35.5	39.1	37.0
Axillary	36.8 (0.6)	35.4	39.2	36.8

[a] Total of 180 measurements per site.

Table 3
Mean temperature difference from core temperature at each site according to range of core temperature

		Difference from core temperature, mean (SD), °C [b]			
Core temperature [a]	Core temperature, mean (SD), °C	Oral	Ear	Temporal	Axillary
Hypothermic (n = 3)	35.5 (0.3)	-0.8 (0.2)	-0.3 (0.7)	-0.6 (0.1)	-0.1 (0.3)
Normothermic (n = 54)	37.1 (0.4)	0.1 (0.3)	-0.3 (0.5)	0.03 (0.5)	0.2 (0.4)
Hyperthermic (n = 3)	38.6 (0.6)	0.5 (0.8)	-0.8 (0.2)	0.3 (0.1)	0.6 (0.8)

[a] Hypothermic includes pulmonary artery temperatures less than 36°C, normothermic includes pulmonary artery temperatures from 36°C to 38°C, and hyperthermic includes pulmonary artery temperatures greater than 38°C.
[b] Negative differences indicate that the noninvasive temperature measurement is lower than the pulmonary artery temperature; positive differences indicate that the noninvasive temperature measurement is higher than the pulmonary artery temperature.

traceable to the National Institute of Standards and Technology by using a controlled water bath. Mean (standard deviation) differences between the certified thermometer and the pulmonary artery thermistor were -0.07°C (0.19°C) at 35.9°C, -0.07°C (0.13°C) at 36.7°C, and -0.08°C (0.15°C) at 38.3°C.

The difference between the pulmonary artery temperature and the noninvasive temperature at each time point was calculated and plotted as described by Bland and Altman.[24] The accuracy (mean difference of all the pairs for each noninvasive site), precision (standard deviation), and confidence limits (mean difference ± 1.96 x standard deviation) of each noninvasive method relative to the pulmonary artery temperature were described. The pulmonary artery temperature, rather than the mean of the pulmonary artery temperature and the noninvasive temperature,[25] was used to allow comparison against a single standard. The differences between the pulmonary artery temperature and each noninvasive temperature were not significantly different across the 3 measurement times; thus, the data were aggregated for analysis. In a manner consistent with previous research,[7,26] a clinically significant difference was defined a priori as greater than ±0.5°C from pulmonary artery temperature, and the number of data pairs outside the ±0.5°C limits were analyzed. For all analyses, α was set at .05.

Results

Demographics of the study participants are presented in Table 1. The overall temperature data are summarized in Table 2. The pulmonary artery temperature in the study sample ranged from 35.3°C to 39.4°C, with individual fluctuations of -0.3°C to 0.2°C during the 1-hour study period. The temperature patterns were stable (less than ±0.1°C/h) in 82% of the patients. A total of 3 patients had core temperatures greater than 38°C, and 3 had core temperatures less than 36°C. The accuracy of each method varied with the level of the pulmonary artery temperature (Table 3). However, the study was limited by the small number of patients who had core temperatures outside of normal limits; thus statistical analysis of the accuracy and precision for these subsets was not performed. Ambient temperature, which ranged from 15.3°C to 21.4°C, did not affect pulmonary artery core temperature or any of the differences between pulmonary artery temperature and noninvasive temperature measurements.

Figure 2 shows the 180 measurements (60 triplicate sets) obtained to compare oral and pulmonary artery temperature measurements. The accuracy was 0.09°C and the precision was 0.43°C, indicating that the oral temperatures slightly underestimated the

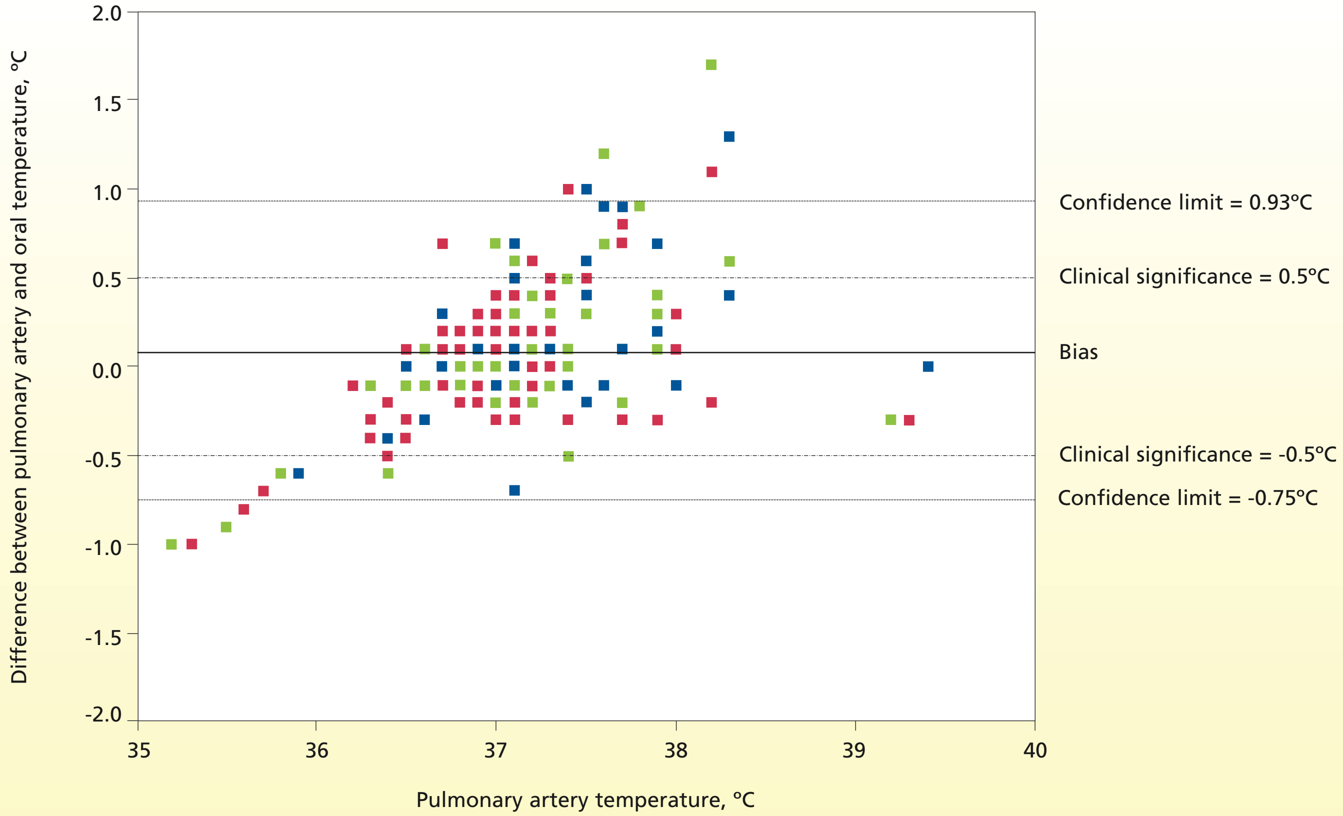

Figure 2 Difference between pulmonary artery and oral temperature. The bias was 0.09°C (SD 0.43°C), indicating that the oral temperatures tended to underestimate the pulmonary artery temperature.

pulmonary artery temperature. The confidence limits ranged from -0.75°C to 0.93°C. Of the 180 data points, 34 (19%) were outside the ±0.5°C range.

Figure 3 shows the 180 measurements (60 triplicate sets) obtained to compare ear-based and pulmonary artery temperature measurements. The accuracy was -0.36°C and the precision was 0.56°C, which indicates that the ear-based measurements overestimated the pulmonary artery temperature. The ear-based temperature measurements also were the least precise of the 4 methods, with the confidence limits ranging from -1.46°C to 0.74°C. Of the 180 data points, 88 (49%) were outside the ±0.5°C range.

Figure 4 shows the 180 measurements (60 triplicate sets) obtained to compare temporal artery and pulmonary artery temperature measurements. The accuracy was -0.02°C with a precision of 0.47°C, which indicates that the temporal artery measurements slightly overestimated the pulmonary artery temperature. The confidence limits ranged from -0.92°C to 0.88°C. Of the 180 data points, 36 (20%) were outside the ±0.5°C range. The temporal artery temperature had an outlier (pulmonary artery temperature > temporal artery temperature by 2.6°C-2.9°C). This patient was diaphoretic and had a fan blowing across the face.

Figure 5 shows the 180 measurements (60 triplicate sets) obtained to compare axillary and pulmonary artery temperature measurements. The accuracy was 0.23°C and the precision was 0.44°C, indicating that the axillary temperature measurements underestimated the pulmonary artery temperature. The confidence limits ranged from -0.64°C to 1.12°C. Of the 180 data points, 49 (27%) were outside the ±0.5°C range.

The oral and temporal artery temperature measurements agreed closely with the pulmonary artery temperature and had similar precision.

The mode of oxygen delivery affected the oral temperatures (Figure 6). Patients who were intubated had significantly ($P = .001$) higher temperatures (mean 0.3°C, SD 0.3°C greater than pulmonary artery temperature) than did patients who received oxygen via nasal cannula (mean 0.2°C, SD 0.5°C less than pulmonary artery temperature) or no supplemental oxygen (mean 0.1°C, SD 0.2°C less than pulmonary artery temperature).

The administration of vasopressors did not affect the difference between the temporal artery and pulmonary artery temperature measurements. Patients

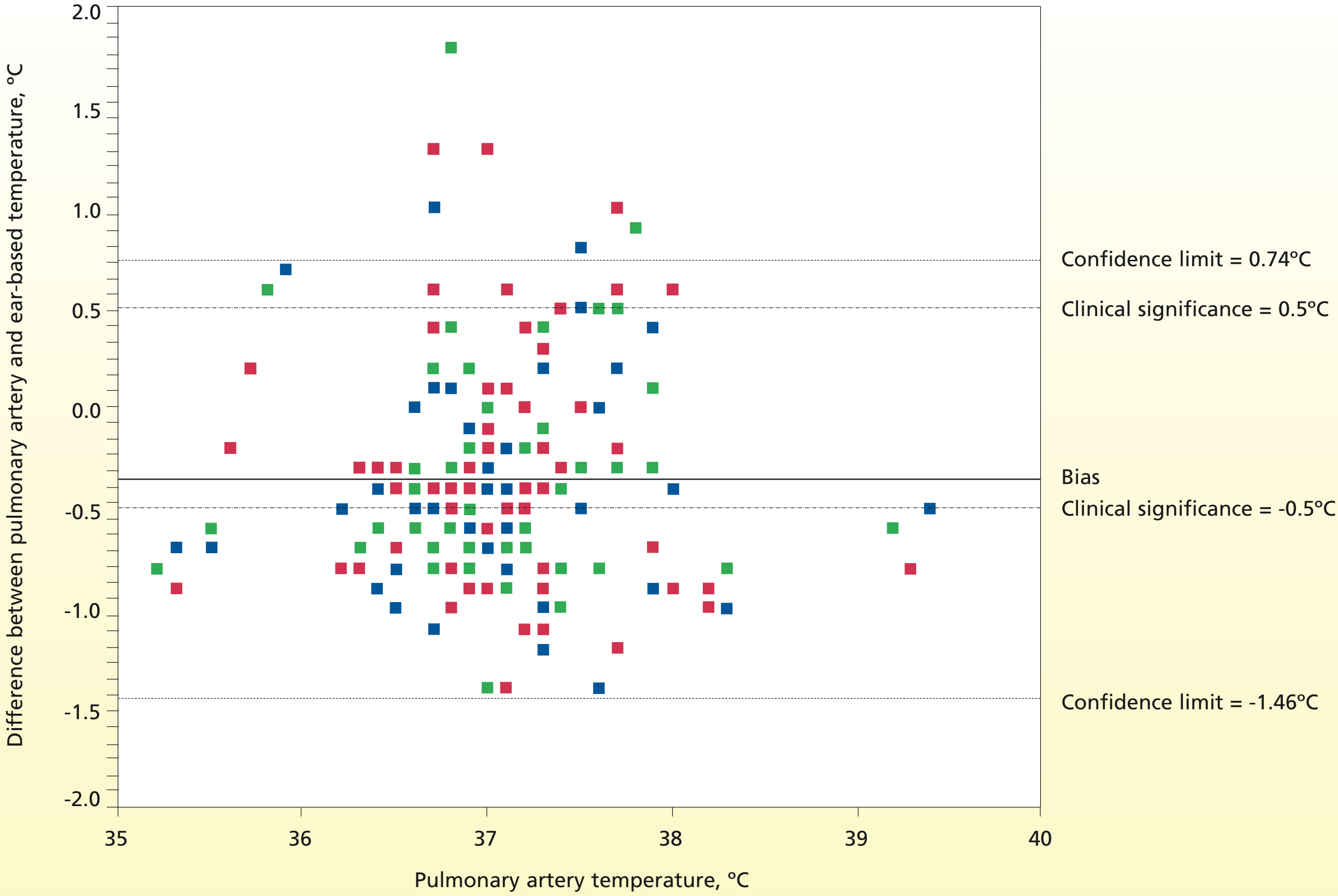

Figure 3 Difference between pulmonary artery and ear-based temperature. The bias was -0.36°C (SD 0.56°C), indicating that ear-based temperatures tend to overestimate the pulmonary artery temperature. Note the wide variability of ear-based temperature measurements.

receiving 1 or more vasopressors (n = 11) had a mean difference of -0.16°C (SD 0.4°C) compared with patients not receiving vasoconstrictive medications (n = 49), who had a mean difference of 0.5°C (SD 0.5°C). Of note, as described in Table 1, the vasopressor dosages were relatively small; therefore, further study of this effect in patients receiving higher dosages is needed.

Discussion

The oral and temporal artery temperature measurements agreed closely with the pulmonary artery temperature, with mean differences less than 0.1°C. The precision measurements of the oral and temporal artery measurements were comparable, as indicated by the confidence limits and the number of data points exceeding the ±0.5°C temperature range. The axillary temperature measurements underestimated the pulmonary artery temperature, although the precision of temporal artery measurements was comparable to the precision of the oral and temporal artery temperature measurements. The ear-based temperature measurements were the least accurate and precise. The confidence limits for all 4 noninvasive measurements exceeded the ±0.5°C range.

Although the oral temperature measurements in intubated patients were statistically significantly higher than oral measurements obtained in patients receiving supplemental oxygen via nasal cannula or no supplemental oxygen, the difference was not clinically significant (>0.5°C difference). These results are consistent with results of previous studies[6,12] and the state-of-the-science reviews by Fallis[8] and Hooper and Andrews.[9]

Measurement of temporal artery temperature is a relatively new method. In the study by Carroll et al,[18] temporal artery measurements obtained by using the combined forehead and behind-the-ear method were more accurate (0.16°C) and precise (1.1°C) compared with pulmonary artery temperature ($P = .17$) than were temporal artery measurements obtained from the forehead only (accuracy 1.54°C, precision 1.3°C, $P < .001$). In our study, the combined forehead and behind-the-ear method had even greater accuracy (-0.02°C) and precision (0.47°C; confidence limits -0.92°C to 0.88°C) than those in the study

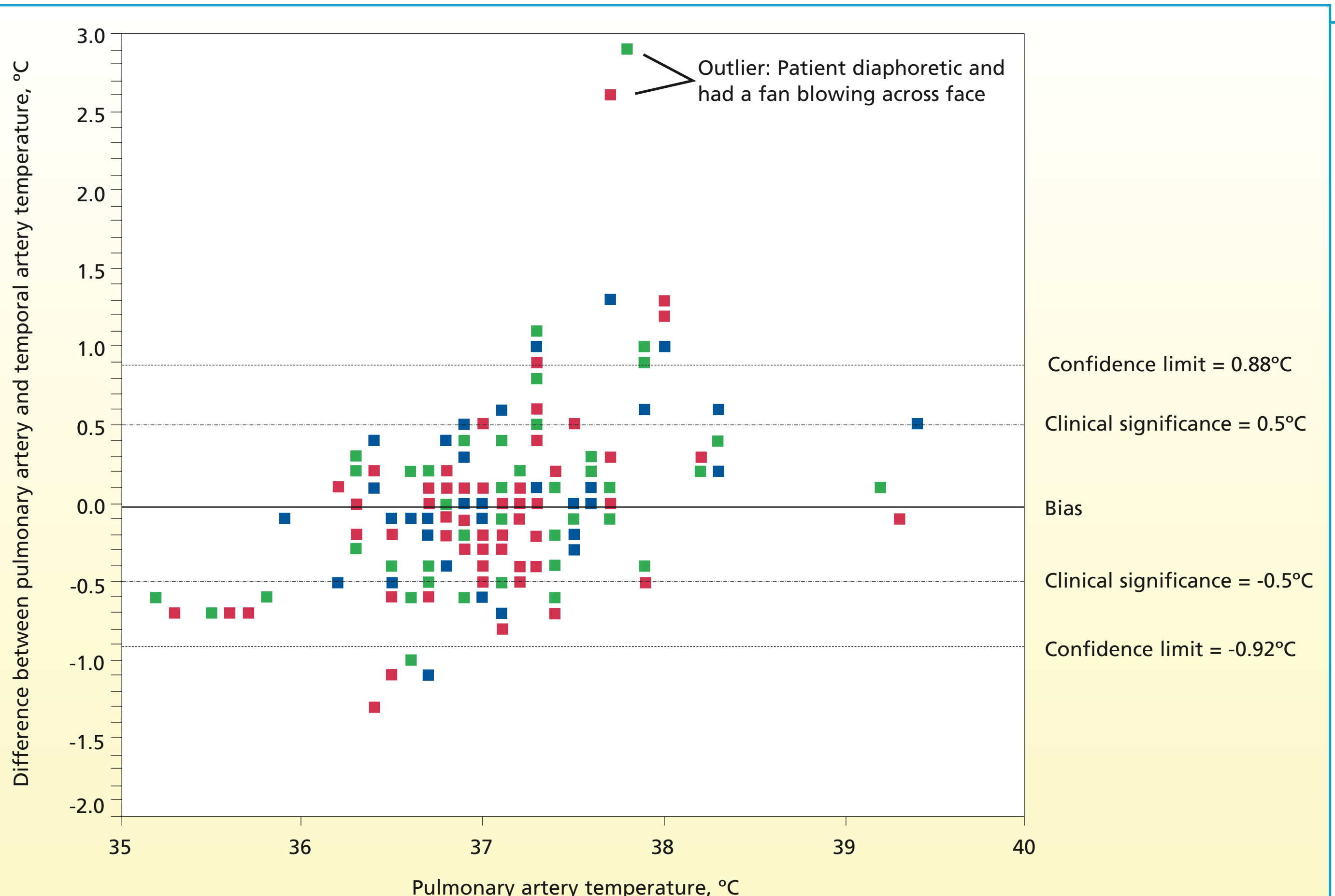

Figure 4 Difference between pulmonary artery and temporal artery temperature. The bias was -0.02°C (SD 0.47°C), indicating that the temporal artery temperature tended to be slightly higher than pulmonary artery temperature. Note the extreme differences in pulmonary artery and temporal artery temperatures in a patient who was diaphoretic and had a fan blowing across the face.

by Carroll et al. Therefore, this combined method (forehead plus behind the ear) as opposed to forehead only is recommended for all patients.

The lack of precision with the ear-based temperature measurement is consistent with what has been reported previously, including the previously discussed studies by Moran et al[14] and Farnell et al.[13] In a study of 38 critically ill patients by Erickson and Kirklin,[10] the mean offset between the pulmonary artery and ear-based temperature was 0.07°C (SD 0.41°C). In a study by Giuliano et al,[7] the precision was 0.54°C for the First Temp Genius II and 0.65°C for the Thermoscan Ear-Pro 1.

In our study, the precision for the ear-based measurements was 0.56°C, and the ear-based method was the least precise of the 4 noninvasive methods. Three patients in our study had pulmonary artery temperatures greater than 38°C. In all 3 patients, the ear-based measurements were higher (range 0.5°C -1.0°C) than pulmonary artery measurements at all time points. In the study of 13 febrile patients (pulmonary artery temperature >37.8°C) by Schmitz et al,[27] the ear-based measurement was higher than the pulmonary artery temperature by 0.15°C (SD 0.44°C), with a sensitivity of 0.87 and a specificity of 0.57 for detecting hyperthermia. In contrast, in the study by Giuliano et al,[7] the ear-based measurement was a mean of 0.17°C less than the core temperature. Given the decreased accuracy and precision of the ear-based measurements in our study and the equivocal results regarding the accurate detection of fever, the ear-based temperature measurement cannot be recommended for use in critically ill patients.

The underestimation of core temperature with the axillary measurements (mean 0.23°C, SD 0.44°C, confidence limits -0.64°C to 1.12°C) is consistent with previous reports.[10,22,28] In the study of critically ill surgery patients by Erickson and Kirklin,[10] the bias was -0.68°C and the precision was 0.57°C. In the study by Lefrant et al,[22] which had patients with demographics similar to those of the patients in our study, the results were similar to our findings (accuracy 0.27°C, precision 0.45°C). In a study[27] of 13 critically ill patients who were febrile (pulmonary

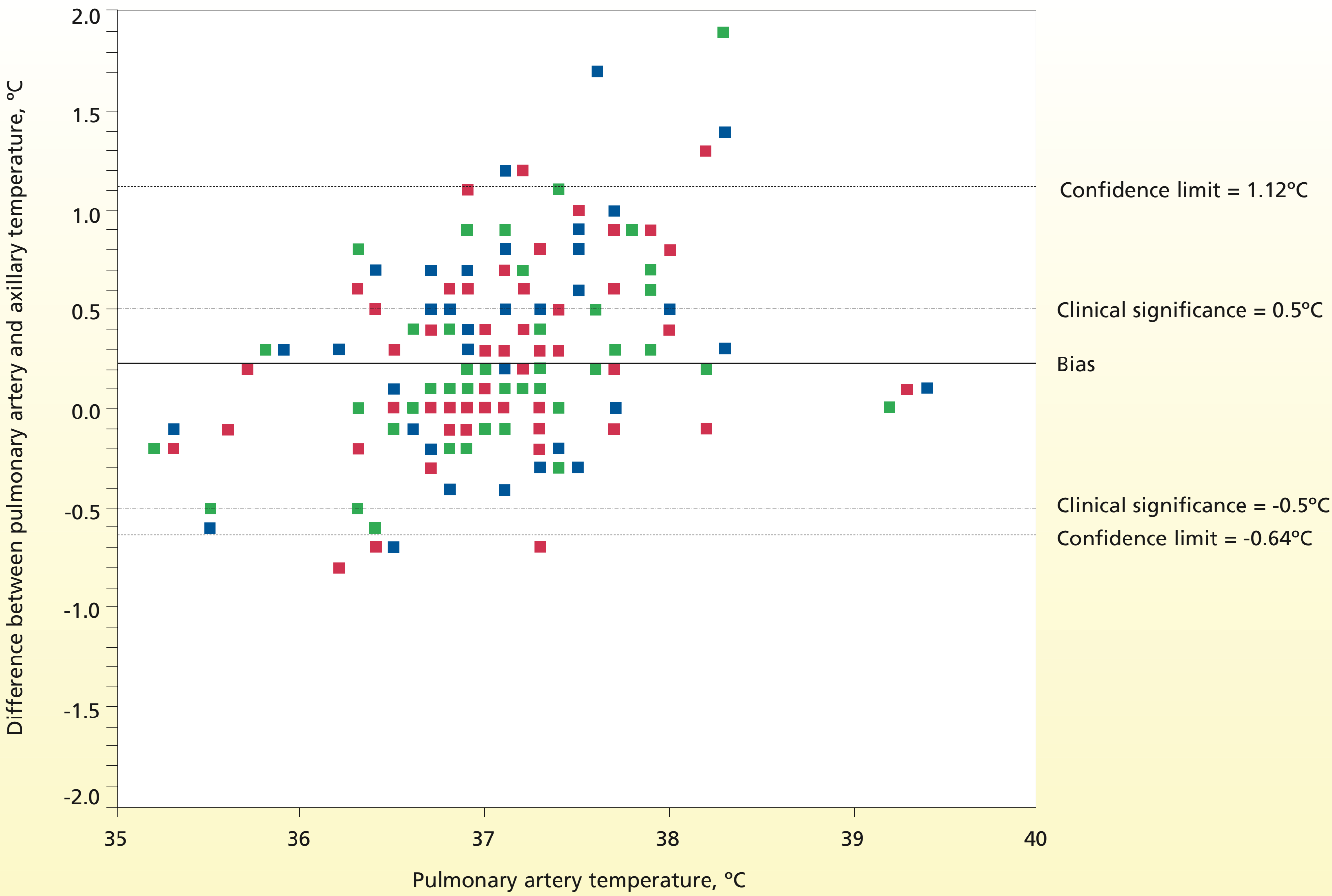

Figure 5 Difference between pulmonary artery and axillary temperature. The bias was 0.23°C (SD 0.44°C), indicating that axillary temperatures tend to underestimate the pulmonary artery temperature.

artery temperature >37.8°C), the axillary temperature was lower than the core temperature (mean 1.12°C, SD 1.6°C), with a sensitivity of 0.14 and a specificity of 1.0 for detection of hyperthermia. In the 3 patients in our study who were febrile, the axillary temperature was lower than the pulmonary artery temperature by 0.07°C to 1.9°C. However, analysis was limited by the small sample. Of interest, in our study, the precision of the axillary method was comparable to the precisions of the oral and temporal artery methods, a finding that most likely reflects the close attention to the procedure for performing the measurement. In clinical practice, less attention to the procedure will decrease the precision of the measurement.

A limitation of our study was the small number of patients who were either hyperthermic (n = 3) or hypothermic (n = 3). Further research is needed on the accuracy and precision of noninvasive methods in patients undergoing therapeutic hypothermia and in patients with fever, particularly those who are diaphoretic or have peripheral vasodilatation due to sepsis. Further study of the temporal artery thermometer is needed in neurosurgical and trauma patients and patients who are receiving high doses of vasoactive medications or large-volume fluid replacement. In addition, research is needed on the effect of airflow across the face on temporal artery measurements, comparison of temporal artery and brain temperature measurements, and temperature measurements in patients who may have abnormal sweating (eg, spinal cord injury with autonomic dysreflexia).

FINANCIAL DISCLOSURES
None reported.

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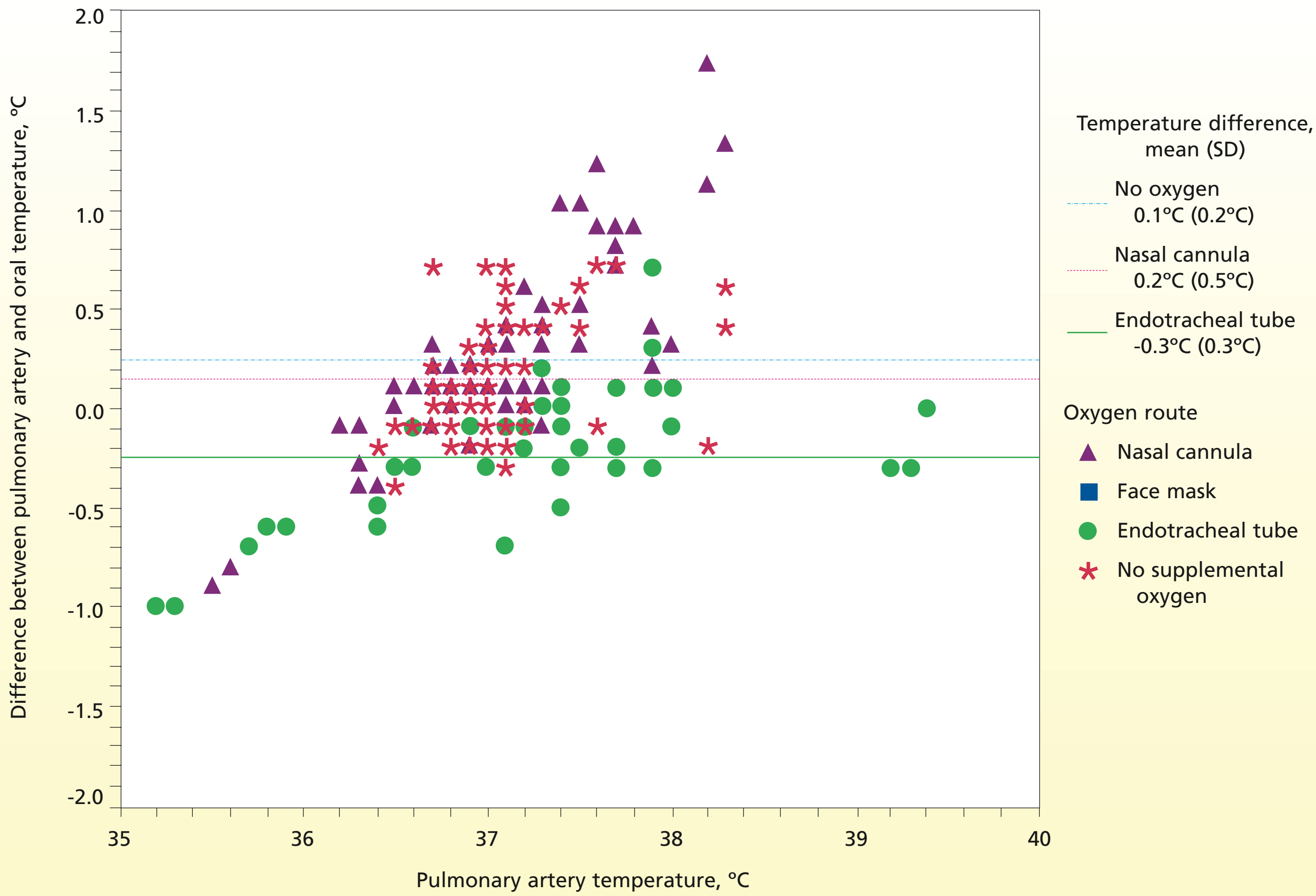

Figure 6 Difference between pulmonary artery and oral temperature depending on the route of oxygen delivery. The route of oxygen delivery affected the oral temperature, although the differences based on route were not clinically significant. In patients who were endotracheally intubated, the oral temperature was significantly higher than the pulmonary artery temperature (mean 0.3°C, SD 0.3°C).

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