Infrared tympanic thermometry in comparison with other temperature measurement techniques in febrile children

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Objective: **To determine whether infrared tympanic thermometry (ITT) measurements more accurately reflect core body temperatures than axillary, forehead, or rectal measurements during fever cycles in children.**

Design: **Prospective cohort study.**

Setting: **Pediatric and cardiac intensive care units at a tertiary care children's hospital.**

Patients: **Critically ill children <7 yrs of age with indwelling bladder catheters.**

Interventions: **Simultaneous temperatures were recorded during both febrile and nonfebrile periods using ITT, indwelling bladder (core), axillary, forehead, and indwelling rectal measurements in 36 children.**

Measurements and Main Results: **Overall ITT measurements were 0.03 ± 1.43°F less than core temperature measurements. In comparison, rectal, forehead, and axillary measurements averaged 0.62 ± 1.44, 0.56 ± 1.81, and 1.25 ± 1.73°F less than core temperature measurements. ITT measurements had better agreement with core measurements during increasing and decreasing temperature cycles. Receiver operating characteristic analysis performed on increasing and decreasing temperature cycle data revealed that ITT measurements performed well, with an area under the curve of 0.855 (95% confidence interval, 0.797–0.913) in comparison with rectal measurement area under the curve of 0.777 (95% confidence interval, 0.701–0.853), forehead measurement area under the curve of 0.710 (95% confidence interval, 0.715–0.888), and axillary measurement area under the curve of 0.664 (95% confidence interval, 0.579–0.750).**

Conclusions: **ITT measurements more accurately reflect core temperatures than any other measurement site during febrile and nonfebrile periods in children. ITT measurements are a reproducible and relatively noninvasive substitute for bladder or rectal measurements in febrile children. (Pediatr Crit Care Med 2006; 7:48–55)**

Key Words: axillary; fever; forehead; infrared; rectal; temperature; thermometry

The primary aim in temperature measurement is the assessment of core body temperature, which is relatively constant in the face of fluctuating environmental conditions (1). Temperatures measured through indwelling pulmonary artery catheters remain the gold standard (2). Bladder temperature measurements have been found to closely correlate with pulmonary artery catheter measurements (3, 4). Both methods are invasive and represent a possible source of complications including infection, pneumothorax, thromboemboli, dysrhythmias, and equipment malfunction (5–7). Although rectal temperature monitoring has been used in some studies as an estimate of core temperature, the blood supply to the rectum is limited, which can lead to slower responses to rapid changes in core temperature (8, 9).

Oral temperature measurements were historically considered the standard method for temperature measurement, but more recent studies have shown this mode to be affected by hyperventilation, probe positioning, and by ingestion of warm or cold liquids (10, 11). The axillary temperature is a favored site for temperature measurement by parents, children, and caregivers because of its ease of use and low risk of injury; however, these measurements can be affected by ambient temperatures and by changes in skin perfusion (12, 13).

Infrared tympanic thermometers have been studied extensively in adults and children as a method to evaluate core temperature. The studies concerning its accuracy have been conflicting. The blood supply of the tympanic membrane from the common carotid artery is shared with the hypothalamus. The blood supply to the ear canal and the tympanic membrane is from the maxillary and middle meningeal arteries, which are branches of the external carotid artery (14). Because both the ear canal and the tympanic membrane have no inherent metabolic activity, the local temperature is determined primarily by the associated blood supply. Therefore, the tympanic membrane temperature should closely represent the hypothalamic temperature.

Several studies in adult intensive care units have compared infrared tympanic thermometry (ITT) with rectal, oral, and pulmonary artery temperature measurements. Milewski et al. (15) concluded that rectal and tympanic temperatures correlated with pulmonary artery catheter measurements, (r = .93 and .74 respectively). In a similar study conducted by

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Klein et al. (16), ITT measurements had good correlation ($r = .91$) with pulmonary artery catheter measurements, and the authors thus concluded that ITT was an adequate substitute for pulmonary artery catheter temperature measurement. Although both studies suggest good correlation between ITT and pulmonary artery temperature measurements, neither addressed the agreement nor accuracy between these two temperature assessment techniques.

There is a paucity of studies in children comparing core body temperature measurement methods (pulmonary artery catheter or bladder) with the most commonly used home methods such as axillary, ITT, rectal, or forehead. In addition, few studies have examined the accuracy of various measurement methods during febrile episodes. A pediatric emergency room study of young children with fever compared ITT and axillary measurements and noted a sensitivity of 0.55 and 0.48, respectively, in comparison with rectal temperatures in detecting fever (17). The authors concluded that neither tympanic membrane nor axillary temperatures can reliably detect fever in young children. In a prospective study in a pediatric intensive care unit, Romano et al. (18) compared pulmonary artery catheter, rectal, axillary, and ITT measurements. These authors concluded that rectal temperature was better than axillary in estimating core temperatures and that an infrared tympanic device performed similarly to the rectal probe.

The current study was designed to test the hypothesis that ITT measurements more accurately reflect core body temperatures than axillary, forehead, or rectal measurements during both febrile and nonfebrile periods in children.

MATERIALS AND METHODS

Subjects. This study was approved by the Investigational Review Board at Cincinnati Children's Hospital Medical Center, and informed consent was obtained from each subject's parent or legal guardian. All children <7 yrs of age who had indwelling bladder catheters inserted after admission to the pediatric and cardiac intensive care units at Cincinnati Children's Medical Hospital Center between October 2000 and October 2002 were evaluated for inclusion in this study. Patients were excluded if they: 1) required induced hypothermia; 2) required an overhead warmer during the study; 3) were diagnosed with diabetes insipidus; 4) had urine output of <1 mL·kg^{-1}·hr^{-1}; 5) were diagnosed with otitis externa or had drainage from either ear or mastoiditis; 6) were wearing a hearing aid in the ear in which the temperatures were to be taken; 7) had any contraindication for rectal probe placement; 8) were diagnosed with anatomic abnormalities that would affect temperature measurement at the ear, forehead, axilla or rectum; or 9) had a platelet count of <50,000/μL or absolute neutrophil count of <500/μL.

Instruments. Temperatures were obtained from the tympanic membrane, forehead, axillary, rectal, and bladder sites. The Braun Thermoscan (IRT 3020 and IRT 3520, Braun GmbH, Kronberg, Germany) was used for the infrared detection of tympanic membrane temperatures. The Thermoscan devices were calibrated using water bath methodology by the manufacturer before use in the study. The ear was tugged to straighten the external auditory canal. In children <1 yr of age, the ear was pulled posteriorly, whereas in older children, the ear was pulled superiorly and posteriorly. The probe was placed snugly into the external auditory canal. The Philips SensorTouch temple thermometer (HF370, Philips Electronic North America Corporation, Chicago, IL) was used for forehead temperatures by following the manufacturer's instructions. A Turbo-Temp Digital thermometer (Alaris Medical Systems, San Diego, CA) was used for all axillary temperatures following the manufacturer's instructions. An indwelling Mon-a-therm rectal probe (Mallinckrodt Medical, St. Louis, MO) was inserted in all enrolled patients, with the position of the tip of the probe 3 cm into the child's rectum. The probe was taped to the leg. The rectal probe position was frequently assessed by the nurses and repositioned if displaced. Bladder temperatures were monitored using the indwelling RSP Foley Catheter with 400 Series thermistor (Respiratory Support Products Inc, San Diego, CA). The bladder catheter sizes ranged from 8 to 12 Fr. The catheters were available in the pediatric and cardiac intensive care units for the nursing staff to insert in patients when a urinary catheter was ordered. The bladder temperature monitor was set every morning to alarm if the patient's temperature increased by 1°F above the baseline temperature. The Philips SensorTouch Turbo-Temp, Mon-a-therm, and RSP Foley Catheter devices were purchased new from each company, with standard calibration performed before packaging.

Procedure. Two clinical research nurses received extensive training on all temperature monitoring devices and were responsible for all patient enrollment, data collection, and data entry. Temperatures from all five body sites were measured at baseline. For the purposes of this study, bladder temperature measurements were designated as the core temperature. Fever was defined as a core temperature of ≥100.4°F. Throughout the study, when temperature measurements were obtained, they were measured from all five sites in a rapid sequential manner. After initial baseline measurements, the core (bladder) temperature monitoring device was set to ensure that it would alarm for an increase of 1°F above the baseline temperature. Temperatures from all sites were monitored and recorded hourly and designated as "steady-state" measurements. Once the core temperature monitor alarm was activated, the bedside nurse immediately contacted the research coordinator. The research coordinator went directly to the patient's bedside and initiated temperature measurements every 5-mins (designated as "5-min measurements"). Temperatures were monitored from each site every 5-mins until the core temperature returned to stable baseline or were constant (<0.5°F of variability for three consecutive measurements taken 5 mins apart). A change in core temperature (increasing or decreasing) was defined as a change of ≥1.5°F. Plateau measurements were defined as temperature measurements obtained during stable core temperatures (no change in temperature of >1°F) during 1-hr of monitoring.

Analysis. Demographic variables were characterized by mean and standard deviations. Mean temperatures were compared for all observations at each measurement site and for each of the four temperature measurement periods: 1) steady state; 2) increasing 5-min; 3) plateau; and 4) decreasing 5-min. Each observation consisted of measurements from all five measurement sites. Temperature measurement agreement between sites were analyzed using the procedures described by Bland and Altman (19, 20). Mean differences between temperatures from each site and core temperatures were calculated along with the standard deviations of the differences. The standard deviations were calculated using a one-way repeated measures analysis of variance with subject as the classification variable and first-order autoregressive covariance structures to model the serial correlations within each subject. These results were then depicted graphically. To determine how similar ITT, forehead, axillary and rectal temperatures were to core temperatures in detecting fevers, receiver operating characteristic analyses of sensitivity and specificity were performed. These analyses were compared between each site and the areas under each curve (AUC) calculated along with 95% confidence intervals. For comparisons between correlated samples, p values were also calculated (AccuROC for Windows, Accumetric Corporation, Montreal, Canada). A Bonferroni correction was used for multiple comparisons. Sensitivity, specificity, positive predictive values, and negative predictive values for each measurement site were then calculated for temperature cutoff ranges between 99.0 and 101.5°F using core temperatures as the index values.

RESULTS

During the study time period, 1,125 patients were evaluated for inclusion in the study. Of those patients evaluated, 387 were eligible for enrollment. A total of 61 patients were approached for consent, and 37 patients were enrolled. One patient had data collected only from the bladder and rectal sites and was excluded from the study. Therefore, 36 patients were analyzed. The patients' ages ranged from 0 to 77 months (mean, 20.0 ± 18.6 months), with a mean weight of 9.9 ± 4.4 kg and a male-to-female ratio of 21:15. Diagnoses included airway reconstructive surgery (n = 9), cardiac disease/surgery (n = 7), lower respiratory tract infection (n = 6), sepsis/systemic inflammatory response syndrome (n = 2), liver transplant (n = 2), intracranial bleeding (n = 2), seizures (n = 2), apparent life-threatening event (n = 2), near drowning (n = 1), diabetic ketoacidosis (n = 1), bone marrow transplantation (n = 1), and trauma (n = 1).

A total of 920 observations were recorded. Eighteen observations were excluded, 17 due to missing data from one or more sites and one due to missing time records. Thus, 902 total observations from five different sites (4,510 temperature measurements) were analyzed. Of the 36 patients analyzed, 19 (53%) had no 5-min measurements, as the core temperature alarm was never activated. The remaining 17 patients activated the core temperature alarm during 28 separate episodes, therefore initiating the 5-min measurements. Of these 28 episodes, nine were associated with a ≥1.5°F temperature change, four increasing and five decreasing. The change in temperature during these episodes ranged from 1.5 to 2.6°F.

Temperature measurement agreement between each of the four sites (ITT, rectal, forehead, and axillary) and core temperature are noted graphically in Figures 1–4. In the Figures, the differences between each temperature measurement from the selected site and the paired core temperature are plotted against the average of the selected site and core temperature. The mean ± SD differences between each temperature measurement site and core temperature are noted in Table 1. This table presents data on all study measurements and measurements obtained during each of the four distinct measurement periods (steady state, increasing 5-min, plateau, and decreasing 5-min). ITT and core temperature measurements were very similar, with an absolute mean difference ranging between 0.01 and 0.16°F and an overall mean difference of 0.03 ± 1.43°F. ITT measurements exhibited the smallest mean difference from core temperature across all measurement periods when compared with all other temperature measurement sites. Axillary temperatures demonstrated the greatest mean difference from core temperature across all measurement periods in comparison with all other temperature measurement sites (1.08 ± 1.98 to 1.95 ± 1.80°F). In examining only the 5-min measurement periods during which core temperatures were increasing or decreasing, ITT measurements exhibited the smallest mean difference from core temperature in comparison with all other temperature measurement sites (0.09 ± 1.23 to 0.16 ± 1.12°F). ITT and rectal temperature measurements displayed the least amount of variability (SD = 1.43 and 1.44, respectively), and forehead and axillary demonstrated the most variability overall (SD = 1.81 and 1.73, respectively).

The sensitivity, specificity, and positive and negative predictive values for each temperature measurement site in comparison with core temperature between ranges of 99.0 and 101.5°F are noted in Tables 2 and 3. Table 2 includes these calculations for all 902 temperature observations in the study. Table 3 includes calculations only for those 268 temperature observations obtained during the increasing and decreasing 5-min periods. Sensitivity and specificity have been further summarized with receiver operating characteristic curves in Figure 5 for temperatures measured during the increasing and decreasing 5-min periods. In this figure, the temperature measure-

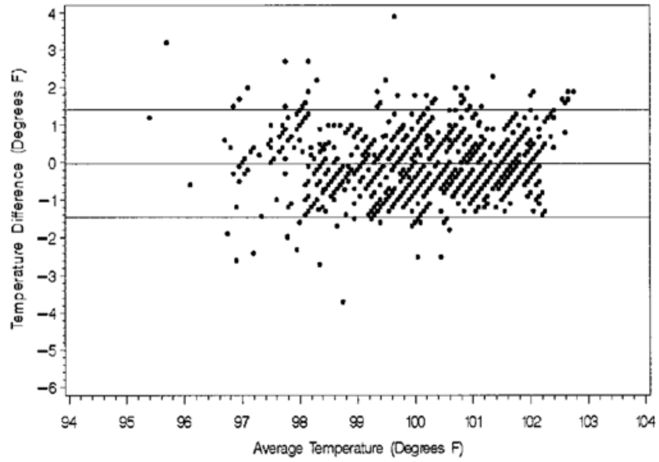

Figure 1. Comparison of the difference between each infrared tympanic thermometry and core (bladder) paired temperature measurements. The *middle horizontal line* represents the mean difference in these two measurements, and the *other horizontal lines* represent 2 SD above and below the mean difference.

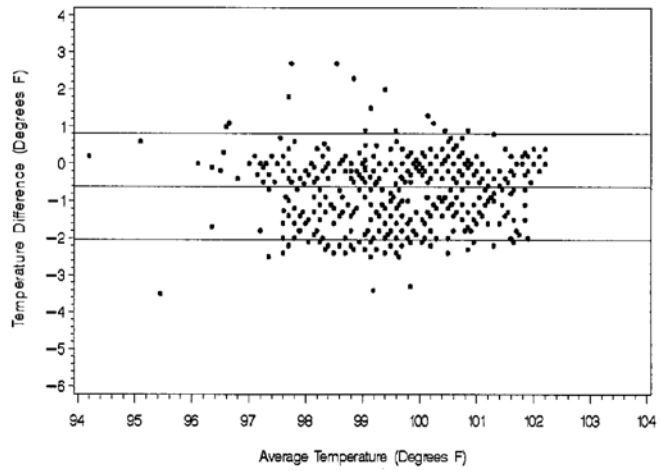

Figure 2. Comparison of the difference between each rectal and core (bladder) paired temperature measurements. The *middle horizontal line* represents the mean difference in these two measurements, and the *other horizontal lines* represent 2 SD above and below the mean difference.

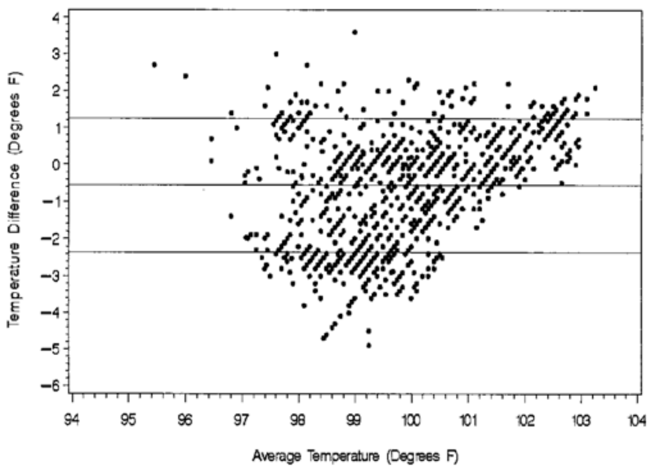

Figure 3. Comparison of the difference between each forehead and core paired temperature measurements. The *middle horizontal line* represents the mean difference in these two measurements, and the *other horizontal lines* represent 2 SD above and below the mean difference.

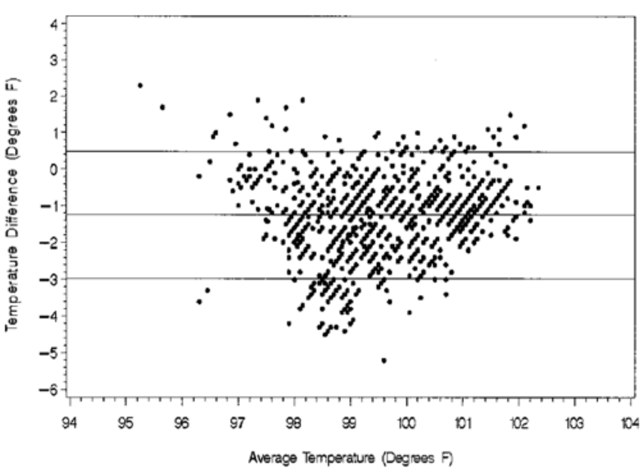

Figure 4. Comparison of the difference between each axillary and core paired temperature measurements. The *middle horizontal line* represents the mean difference in these two measurements, and the *other horizontal lines* represent 2 SD above and below the mean difference.

ment site with the greatest AUC represents the best measurement site. A perfect device would have an AUC equal to 1. Table 4 presents the AUC values for each site along with the corresponding 95% confidence limits. ITT measurements were more representative of core measurements, with larger AUCs in comparison with the other three sites for all measurements and for temperatures obtained during the steady-state period. For all measurements, the AUC for ITT was significantly greater than forehead and axillary temperatures (0.906 vs. 0.781 vs. 0.847; $p < .0001$). During the increasing and decreasing 5-min measurement periods, the AUC for ITT was significantly greater than axillary (0.855 vs. 0.664, $p = .008$). During plateau periods, rectal measurements performed better than other sites.

DISCUSSION

Over the past decade, ITT has gained wider acceptance. Nurses, parents, and children have rated it higher in terms of rapidity, ease of use, cleanliness, safety, and cost effectiveness (21–24). Patient cooperation, the presence of cerumen in the external auditory canal, and otitis media have been shown to have an insignificant effect on the reliability and accuracy of ITT measurements (25–27). Many studies have been published looking at the accuracy of ITT when compared with core temperature measurement techniques (28). Although the conclusions have been heterogeneous, ITT remains in widespread use in pediatric practices and emergency rooms (29).

In the intensive care unit, temperature measurement is an essential component in patient assessment and management decisions. An optimal temperature measurement device should be minimally invasive and provide rapid results in a reliable, accurate, and safe manner to support clinical decisions. Axillary and forehead temperatures are minimally invasive but are inaccurate and significantly influenced by ambient tempera-

Table 1. Mean ± 2 SD differences between each temperature measurement site and core (bladder) temperature for all measurements and for each of the four temperature measurement periods

			5-Min Measurements		
	All Measurements	Steady State Measurements	Increasing 5-Min Measurements	Plateau Measurements	Decreasing 5-Min Measurements
ITT	−0.03 ± 1.43	0.01 ± 1.87	−0.09 ± 1.23	−0.10 ± 1.24	0.16 ± 1.12
Rectal	−0.62 ± 1.44	−0.42 ± 1.77	−1.13 ± 0.41	−0.54 ± 1.03	−0.74 ± 1.01
Forehead	−0.56 ± 1.81	−0.06 ± 2.11	−0.57 ± 1.50	−0.25 ± 1.78	−2.11 ± 0.84
Axillary	−1.25 ± 1.73	−1.08 ± 1.98	−1.17 ± 1.13	−1.11 ± 1.63	−1.95 ± 1.80

ITT, infrared tympanic thermometry.

Table 2. Sensitivity (Sens), specificity (Spec), positive predictive value (PPV), and negative predictive value (NPV) for each temperature measurement site in comparison with core (bladder) temperature

	Tympanic				Rectal				Forehead				Axillary			
Cutoff	Sens	Spec	PPV	NPV	Sens	Spec	PPV	NPV	Sens	Spec	PPV	NPV	Sens	Spec	PPV	NPV
99.0	1.00	0.43	0.65	0.99	0.92	0.59	0.70	0.87	0.75	0.56	0.64	0.68	0.76	0.81	0.81	0.77
99.1	1.00	0.45	0.66	0.99	0.87	0.65	0.73	0.83	0.75	0.59	0.66	0.69	0.75	0.83	0.82	0.76
99.2	0.99	0.49	0.67	0.99	0.87	0.70	0.76	0.83	0.73	0.62	0.67	0.69	0.74	0.85	0.84	0.76
99.3	0.99	0.53	0.69	0.98	0.87	0.71	0.76	0.83	0.72	0.64	0.68	0.69	0.70	0.87	0.85	0.73
99.4	0.98	0.56	0.70	0.96	0.84	0.73	0.76	0.81	0.70	0.67	0.69	0.68	0.67	0.89	0.87	0.72
99.5	0.97	0.59	0.72	0.95	0.84	0.73	0.76	0.81	0.69	0.67	0.69	0.68	0.63	0.91	0.88	0.70
99.6	0.95	0.62	0.72	0.93	0.83	0.76	0.78	0.81	0.69	0.69	0.70	0.68	0.61	0.92	0.89	0.69
99.7	0.94	0.65	0.74	0.91	0.83	0.76	0.78	0.81	0.67	0.73	0.72	0.68	0.60	0.92	0.89	0.69
99.8	0.92	0.68	0.75	0.89	0.81	0.79	0.80	0.79	0.66	0.75	0.74	0.67	0.59	0.93	0.90	0.69
99.9	0.91	0.70	0.76	0.88	0.81	0.79	0.80	0.79	0.64	0.78	0.75	0.67	0.57	0.94	0.91	0.67
100.0	0.89	0.72	0.77	0.86	0.78	0.84	0.83	0.78	0.63	0.81	0.78	0.68	0.54	0.95	0.91	0.66
100.1	0.88	0.75	0.79	0.85	0.74	0.88	0.87	0.76	0.62	0.82	0.79	0.68	0.51	0.96	0.94	0.65
100.2	0.85	0.77	0.79	0.83	0.74	0.88	0.87	0.76	0.61	0.86	0.82	0.68	0.48	0.97	0.95	0.64
100.3	0.83	0.79	0.81	0.81	0.67	0.93	0.91	0.73	0.59	0.87	0.83	0.67	0.44	0.98	0.96	0.62
100.4	**0.80**	**0.81**	**0.81**	**0.79**	**0.67**	**0.93**	**0.91**	**0.73**	**0.57**	**0.87**	**0.83**	**0.66**	**0.40**	**0.98**	**0.96**	**0.61**
100.5	0.77	0.84	0.84	0.78	0.58	0.97	0.96	0.69	0.55	0.90	0.85	0.66	0.35	0.99	0.97	0.59
100.6	0.74	0.88	0.87	0.76	0.58	0.97	0.96	0.69	0.53	0.90	0.85	0.65	0.32	0.99	0.97	0.58
100.7	0.70	0.91	0.89	0.74	0.48	0.99	0.97	0.64	0.52	0.92	0.87	0.64	0.28	0.99	0.97	0.57
100.8	0.66	0.92	0.90	0.72	0.48	0.99	0.97	0.64	0.49	0.93	0.88	0.64	0.25	1.00	0.98	0.56
100.9	0.63	0.94	0.92	0.71	0.39	1.00	0.99	0.61	0.49	0.95	0.90	0.64	0.21	1.00	0.99	0.55
101.0	0.60	0.95	0.93	0.69	0.29	1.00	1.00	0.57	0.46	0.95	0.90	0.63	0.16	1.00	0.99	0.53
101.1	0.56	0.95	0.93	0.67	0.29	1.00	1.00	0.57	0.45	0.95	0.91	0.62	0.13	1.00	1.00	0.52
101.2	0.51	0.97	0.94	0.65	0.24	1.00	1.00	0.55	0.42	0.97	0.93	0.61	0.10	1.00	1.00	0.51
101.3	0.46	0.97	0.94	0.63	0.23	1.00	1.00	0.55	0.41	0.97	0.94	0.61	0.09	1.00	1.00	0.51
101.4	0.42	0.97	0.94	0.61	0.19	1.00	1.00	0.54	0.39	0.97	0.94	0.60	0.07	1.00	1.00	0.51
101.5	0.39	0.98	0.95	0.60	0.19	1.00	1.00	0.54	0.38	0.98	0.96	0.60	0.06	1.00	1.00	0.50

Values are calculated on all measurements (n = 902, 51% with fever) obtained in the study; cutoff points for core temperatures between 99.0°F and 101.5°F are included.

tures (30). Romano et al. (18) compared the performance of ITT, rectal, and axillary thermometers with pulmonary artery catheter temperature measurements in critically ill children. As in the current study, these authors noted that axillary temperature measurements significantly underestimated core temperature and were associated with considerable variability. Rectal temperatures are widely used, yet they are invasive and are associated with patient discomfort, rectal perforations, and concerns regarding inaccuracies with high or low body temperatures (31, 32). Temperature measurements from bladder catheters are highly correlated with esophageal and pulmonary artery catheters and can be used as a good estimate of core temperature (33). Although bladder temperature measurements represent an excellent approximation of core temperature, this technique is invasive and may be associated with urethral trauma and urinary tract infections (33).

The primary objective of our study was to determine whether ITT measurements are an accurate and reliable indicator of core temperature in febrile children when compared with bladder, rectal, axillary, and forehead measurements. Our data suggest that temperature measurements with ITT have close agreement with core temperature, varying by a mean of 0.01 to 0.16°F, regardless of whether the patient's temperature is at steady state or in flux. ITT had greater overall agreement with core temperature than rectal, forehead, and axillary measurement sites.

Receiver operating characteristic analysis is an excellent tool in assessing the performance of a diagnostic instrument. Although ITT, rectal, and axillary measurement sites had comparable receiver operating characteristic AUCs when all measurements were compared, there were large differences noted during periods of increasing or decreasing 5-min measurements. During these states of temperature flux, ITT had a much larger AUC then any other measurement site, indicating that the performance of ITT excelled in accurately approximating core temperature measurements during these dynamic conditions. Ideally, a measurement device should have both high sensitivity and high specificity. Using a 100.4°F temperature cutoff, our data suggest that the use of the rectal thermometer is associated with normal temperature measurements in truly febrile patients 33% of the time in comparison with 20% of the time using ITT (Table 2). This difference in fever detection is even more pronounced during periods when the patient's body temperature is in flux (Table 3). Decisions regarding the most appropriate device to be utilized in any given patient care setting must balance the costs of overdiagnosis and treatment of false-positive fever with the costs of underdiagnosis and lack of treatment of undetected fever. Our data suggest that ITT measurements agree with core temperature better than rectal, forehead, and axillary temperature measurement sites.

Our data support previous studies that have noted a lack of agreement between rectal and ITT measurements. Benzinger (14) compared rectal with ITT and esophageal temperature measurements and concluded that rectal temperature measurements correlated poorly with the esophageal and tympanic membrane temperatures. Furthermore, changes in rectal temperature measurements have been noted to be delayed in comparison with temporal and pulmonary arterial temperatures in children after treatment

Table 3. Sensitivity (Sens), specificity (Spec), positive predictive value (PPV), and negative predictive value (NPV) for each temperature measurement site in comparison with core (bladder) temperature

	Tympanic				Rectal				Forehead				Axillary			
Cutoff	Sens	Spec	PPV	NPV	Sens	Spec	PPV	NPV	Sens	Spec	PPV	NPV	Sens	Spec	PPV	NPV
99.0	1.00	0.18	0.82	0.91	0.92	0.43	0.86	0.59	0.63	0.71	0.89	0.34	0.72	0.80	0.93	0.43
99.1	1.00	0.21	0.83	0.92	0.83	0.50	0.86	0.44	0.62	0.71	0.89	0.33	0.71	0.84	0.94	0.44
99.2	1.00	0.25	0.83	0.93	0.82	0.50	0.86	0.42	0.60	0.73	0.90	0.33	0.70	0.84	0.94	0.42
99.3	1.00	0.25	0.83	0.93	0.82	0.50	0.86	0.42	0.58	0.73	0.89	0.32	0.67	0.88	0.95	0.41
99.4	0.99	0.25	0.83	0.82	0.77	0.52	0.86	0.38	0.55	0.75	0.89	0.30	0.63	0.91	0.96	0.39
99.5	0.99	0.29	0.84	0.84	0.77	0.52	0.86	0.38	0.53	0.77	0.90	0.30	0.59	0.93	0.97	0.37
99.6	0.97	0.29	0.84	0.70	0.76	0.54	0.86	0.38	0.53	0.77	0.90	0.30	0.57	0.95	0.98	0.37
99.7	0.96	0.30	0.84	0.68	0.76	0.54	0.86	0.38	0.51	0.82	0.92	0.31	0.55	0.95	0.98	0.36
99.8	0.94	0.32	0.84	0.60	0.74	0.55	0.86	0.36	0.48	0.84	0.92	0.30	0.55	0.95	0.97	0.36
99.9	0.93	0.39	0.85	0.61	0.74	0.55	0.86	0.36	0.45	0.88	0.93	0.30	0.51	0.95	0.97	0.34
100.0	0.93	0.43	0.86	0.62	0.71	0.61	0.87	0.35	0.44	0.88	0.93	0.29	0.47	0.96	0.98	0.33
100.1	0.92	0.50	0.88	0.64	0.67	0.66	0.88	0.35	0.43	0.88	0.93	0.29	0.44	0.96	0.98	0.31
100.2	0.89	0.52	0.88	0.56	0.67	0.66	0.88	0.35	0.41	0.93	0.96	0.29	0.41	0.98	0.99	0.30
100.3	0.86	0.52	0.87	0.49	0.59	0.70	0.88	0.31	0.37	0.95	0.96	0.28	0.34	1.00	1.00	0.29
100.4	**0.83**	**0.57**	**0.88**	**0.48**	**0.59**	**0.70**	**0.88**	**0.31**	**0.34**	**0.95**	**0.96**	**0.28**	**0.29**	**1.00**	**1.00**	**0.27**
100.5	0.80	0.64	0.89	0.46	0.50	0.91	0.95	0.32	0.33	0.96	0.97	0.28	0.24	1.00	1.00	0.26
100.6	0.76	0.73	0.92	0.45	0.50	0.91	0.95	0.32	0.33	0.96	0.97	0.27	0.21	1.00	1.00	0.25
100.7	0.75	0.79	0.93	0.45	0.39	0.96	0.98	0.30	0.31	0.98	0.99	0.27	0.18	1.00	1.00	0.24
100.8	0.70	0.84	0.94	0.43	0.39	0.96	0.98	0.30	0.29	0.98	0.98	0.27	0.16	1.00	1.00	0.24
100.9	0.67	0.89	0.96	0.42	0.26	0.98	0.98	0.26	0.28	0.98	0.98	0.27	0.15	1.00	1.00	0.24
101.0	0.63	0.91	0.96	0.39	0.11	1.00	1.00	0.23	0.27	0.98	0.98	0.26	0.11	1.00	1.00	0.23
101.1	0.58	0.91	0.96	0.36	0.11	1.00	1.00	0.23	0.26	0.98	0.98	0.26	0.08	1.00	1.00	0.22
101.2	0.51	0.93	0.96	0.34	0.03	1.00	1.00	0.21	0.24	0.98	0.98	0.25	0.08	1.00	1.00	0.22
101.3	0.44	0.95	0.97	0.31	0.03	1.00	1.00	0.21	0.23	0.98	0.98	0.25	0.06	1.00	1.00	0.22
101.4	0.38	0.95	0.96	0.29	0.00	1.00	1.00	0.21	0.23	0.98	0.98	0.25	0.05	1.00	1.00	0.22
101.5	0.36	0.95	0.96	0.28	0.00	1.00	1.00	0.21	0.21	0.98	0.98	0.25	0.04	1.00	1.00	0.22

Values are calculated on measurements obtained only during increasing and decreasing 5-min measurements (n = 268, 79% with fever) in the study; cutoff points for core temperatures between 99.0°F and 101.5°F are included.

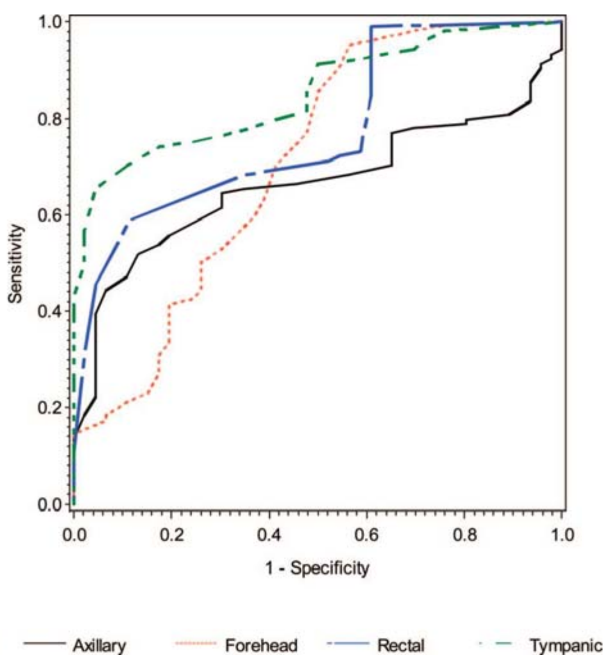

Figure 5. Receiver operating characteristic curves for axillary, forehead, rectal, and infrared tympanic thermometry measurements in comparison with core temperature measurements for the 268 temperature observations obtained during increasing and decreasing 5-min periods. Infrared tympanic thermometry area under the curve was significantly greater than axillary ($p = .008$)

of fever (34, 35). The delay in agreement between rectal and other temperature measurement sites has been referred to as "rectal lag" and has been attributed to the lack of thermoreceptors in the rectum and the physical distance between the rectum and the hypothalamus (34). Early detection of increasing body temperature is important in the timing of blood culture collection in improving the probability of organism detection. Measurement of an elevated rectal temperature that has lagged behind a recent increase in core temperature may adversely affect clinical decision making by diminishing the chances of recovering an organism. The delay in the detection of rectal temperatures may in part explain the lack of agreement between rectal and core body temperature measurements in the current study.

In contrast to the current study, some investigators have questioned the reliability and accuracy of ITT measurements. Maxton et al. (36) studied six different temperature measurement modalities in children during cardiac surgery. Bladder temperature was noted to be the best estimate of pulmonary artery temperature, whereas tympanic measurements were not thought to be reliable. The nature of the temperature change (external cooling and rewarming) may explain the lack of reliability and accuracy of ITT as this temperature change is not of hypothalamic origin. We are not

Table 4. Area under the receiver operating curves (95% confidence intervals) for infrared tympanic thermometry (ITT), rectal, forehead, and axillary measurement sites at each temperature measurement period

	All Measurements	Steady State Measurements	Plateau Measurements	Increasing and Decreasing 5-Min Measurements
ITT	0.906 (0.880–0.924)[a]	0.896 (0.837–0.956)	0.899 (0.872–0.927)	0.855 (0.797–0.913)[b]
Rectal	0.897 (0.878–0.917)	0.893 (0.833–0.953)	0.927 (0.903–0.951)	0.777 (0.701–0.853)
Forehead	0.781 (0.751–0.810)	0.802 (0.715–0.888)	0.868 (0.833–0.904)	0.710 (0.613–0.808)
Axillary	0.847 (0.821–0.873)	0.813 (0.725–0.901)	0.872 (0.838–0.906)	0.664 (0.579–0.750)

[a] $p < .0001$ in comparison with forehead and axillary area under the curves; [b] $p = .008$ in comparison with axillary area under the curves during the increasing and decreasing 5-min measurement period.

able to compare the above results with the current study because our study design specifically excluded subjects who were externally warmed or cooled. Two additional studies have concluded that ITT was inaccurate in comparison with rectal temperature (37, 38). These investigators defined core temperature as that measured by the rectal instrument (38). There is, however, little evidence to support the use of rectal temperature as a gold-standard measure of core temperature (39, 40). Clinical trials that compare one instrument with another may yield misleading results if the established method is not precise, accurate, and repeatable.

There were several limitations to the current study. During the 2-yr study period, we were able to record only 118 measurements, 5-mins apart, during fever episodes in seven patients. Several reasons account for these difficulties. First, the study design was based on estimating a temperature increase of 1°F over baseline. In many cases, once this change occurred, no additional temperature increases were forthcoming. Second, in most instances, once a temperature of 100.4°F was reached, measures were applied by the primary care team to reduce the fever. Third, not all patients admitted to the pediatric and cardiac intensive care units had indwelling bladder catheters, and thus, patients were not enrolled, despite febrile episodes. No bladder catheters were placed for the sole purpose of enrolling the child in this study. Fourth, some bladder catheters were removed in enrolled patients before a temperature increase. Extension of the study findings to the ambulatory pediatric setting is limited because the current study was conducted on sedated inpatients. The results may be dissimilar in patients who are more mobile and less cooperative.

In summary, ITT measurements agreed more closely with core temperature than rectal, forehead, and axillary measurements during both febrile and nonfebrile conditions in children. ITT and rectal temperature measurements have minimal variability when compared with axillary and forehead measurements. Axillary and forehead temperature measurements are inaccurate, highly variable, and have low agreement with core temperatures. Use of axillary and forehead temperature measurements should be discouraged in assessing fever in critically ill children. ITT is a reliable, practical, and accurate method of detecting fevers in children and a less invasive substitute for bladder or rectal measurements.

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