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Tympanic, Infrared Skin, and Temporal Artery Scan Thermometers Compared with Rectal Measurement in Children: A Real-Life Assessment



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ABSTRACT

Introduction: Body temperature measurement in children is of clinical relevance. Although rectal measurement is the gold standard, less invasive tools have become available. We aimed to describe the accuracy of tympanic, infrared skin, or temporal artery scan thermometers compared with rectal measurement to reflect core temperature.

Methods: Rectal (Filac 3000; Covidien, Mechelen, Belgium), tympanic (AccuSystem Genius2 Tympanic Infrared Ear Thermometer, Covidien, Mechelen, Belgium), temporal artery scan (Exergen, Exergen Corp, Watertown, Massachusetts), and infrared (ThermoFlash Contactless Medical Electronic Thermometer, Visiomedlab, Paris, France) body temperature measurements were randomly performed and readings were collected once. Temperature readings were described as median and range, and observations were compared with rectal temperature readings (using Wilcoxon, Bland-Altman, sensitivity, and specificity tests). The child's comfort was assessed by the child, parent, and nurse (using Likert scales) and ease of use was assessed by nurses (using visual analog scale).

Results: Based on observations in 294 (median age = 3.2 years, range = 0.02–17 years) children, the mean difference was 0.49°C (tympanic scan; $P < 0.0001$), 0.34°C (infrared skin scan; $P < 0.0001$), and 0°C (temporal artery scan; $P = 0.9288$), respectively, when compared with rectal temperature readings. Based on visual inspection of Bland-Altman plots, all tools overestimated the temperature at lower body temperature and underestimated the temperature at higher body temperature, resulting in a sensitivity of 22% to 41% and a specificity of 98% to 100% for rectal temperatures above 38°C. The Likert scale scores and the visual analog scale scores for rectal measurement were only slightly higher when compared with the other methods.

Conclusions: All noninvasive techniques underperformed compared with rectal measurement. The temporal artery scan deviations were smallest, but all noninvasive techniques overestimate lower temperatures and underestimate higher temperatures compared with rectal measurement. In our hands, temporal artery scan measurement seems to be second best, but not yet ideal.

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Introduction

Medical decisions related to diagnosis, planning of investigations, or subsequent pharmacologic treatment in children are in part driven by body temperature measurement.^{1–3} In pediatrics, the gold-standard reference to measure core body temperature is by measurement of rectal temperature because this reflects central

core temperature. Although this is considered to be the gold standard in many health care systems, it carries its own drawbacks. This includes discomfort, emotional distress, and—although very rare—possible complications such as perforation or transmission of micro-organisms. In a systematic review, axillary instead of rectal recordings resulted in a pooled difference of 0.85°C (−0.2°C to 1.9°C).^{4,5} In an attempt to avoid the disadvantages of rectal measurement, a range of alternative devices and less noninvasive methods have been introduced, including tympanic,^{6–11} infrared skin scan,^{6,12–15} and temporal artery scan^{16,17} temperature measurement.

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A popular alternative for rectal measurement is the tympanic scan thermometer.^{6–11} This device measures the amount of infrared heat produced by the tympanic membrane of the ear by means of a sensor probe. The tympanic membrane shares its blood supply with the hypothalamus, the thermoregulatory center of the human body. However, this necessitates appropriate application and access to the tympanic membrane. Consequently, the probe needs to be positioned in the auditory external duct in the appropriate angle to the tympanic membrane, which makes it more difficult in young infants or in cases of suspected otitis media, but has indeed been very well validated in, for example, sedated patients or during anesthesia. The infrared skin thermometer is another tool to measure body temperature.^{6,12–15} A sensor probe measures the amount of infrared emitted heat. Consequently, temperature can be measured without direct contact with the child. Specific advantages of the no-touch technique relate to cross-infections or the possibility to measure without disrupting sleep. Finally, temporal artery scan techniques have been developed.^{16,17} Temperature is hereby registered by slow scanning the forehead in the temporal artery region and behind the ear by direct skin contact. The thermometer thereby measures the naturally emitted infrared heat from the temporal arterial supply.

Several comparative studies have been performed in either sedated patients^{9,12} or in specific pediatric subpopulations,^{9,10,14} commonly by comparing 2 devices.^{4–6,8,11,13,15–17} In contrast, investigator-driven studies that simultaneously compare different available assessment tools in a heterogeneous group of pediatric populations commonly admitted in a pediatric hospital is limited. In our study, we aimed to evaluate the accuracy and performance of 3 newer tools when compared with what is considered to be the gold standard; that is, rectal temperature measurement, within a real-life clinical setting. Besides the measurement, we also collected some subjective impressions about the child's comfort (evaluated by the nurse, parent, and child) and the device-specific ease of use (evaluated by the nurse).

Methods

Ethics, enrollment, and clinical study

The study protocol (S 53071) was approved by the ethics board of University Hospitals, Leuven, Belgium. Pediatric patients admitted to different pediatric wards of University Hospitals were included in the study after informed consent of the patients and/or their legal representatives when body temperature assessment was scheduled.

The study protocol had the explicit aim to reflect a real-life assessment. Measurements were collected in every single patient in random order. Using an at-random approach, a rectal body temperature measurement device (Filac 3000; Covidien, Mechelen, Belgium), a tympanic scan thermometer (AccuSystem Genius2 Tympanic Infrared Ear Thermometer; Covidien, Mechelen, Belgium), an infrared skin scan thermometer (ThermoFlash Contactless Medical Electronic Thermometer; Visiomedlab, Paris, France), and a temporal artery scan thermometer (Exergen; Exergen Corp, Watertown, Massachusetts) were used. Measurements were collected consecutively at 1 single time point with a time interval to collect all readings of <5 minutes to avoid physiologic fluctuations.

Measurements were performed according to the product-specific instructions, and nurses were trained before the study on the appropriate use of the different devices. These trainings were formal teaching sessions explaining product-specific issues for appropriate and safe use of the different devices. The presentations and written handout documents were subsequently

provided to the nurses and compliance was intermittently verified by a dedicated study nurse (I. van Gorp). Temperature readings in every individual patient were collected at 1 time point, every child was only included once, and device-specific readings were only performed once in every patient. To reflect the heterogeneous character of the study population, children were included at the emergency department, at the outpatient clinic, at the pediatric day surgery unit and on the medical wards.

In addition to the temperature readings, subjective impressions about the child's comfort (as assessed by the nurse, parent, and child) and the ease of use (assessed by the nurse) were collected. These subjective impressions were quantified based on a Likert scale score (child's comfort, assessed by the child, parent, and nurse, where 1–5 = very well, well, neutral, poor, and very poor comfort, respectively) or a visual analog scale (VAS) score (ease of use, assessed by the nurse, where 0–10 = very good to very poor). The choice for different scores (Likert or VAS) for the assessments of the nurses was to stress the differences between both questions (child's comfort vs ease of use). These data were collected immediately following temperature readings.

Data analysis and statistics

Temperature readings and Likert scale or VAS scores were reported by median and range. Temperature readings as collected with the different measurement tools were compared (using Wilcoxon test). Considering rectal temperature readings as the reference value, temperature readings were compared with this reference value (differences) and graphed according to the Bland-Altman method. Finally, sensitivity, specificity, positive predictive values, and negative predictive values to detect raised body temperature (37.8°C) and fever (38°C) were calculated based on the same rectal reference measurements. Statistics were analyzed using MedCalc (MedCalc Software, Ostend, Belgium), and *P* values < 0.05 were considered significant.

Results

In total, 294 children with a median age of 3.2 years (range = 0.02–17 years) were included. Temperature readings as recorded for the different measurement tools are listed in Table I. Compared with rectal measurement, the mean differences were 0.49°C

Table I

Temperature readings* and subjective evaluation by nurses, parents, and children related to the child's comfort or ease of use.

Temperature measurement device	Median	Range		
Rectal measurement	37.1	35.1–39.5		
Tympanic thermometer	36.6	34.7–39.5		
Infrared skin scan thermometer	36.7	35.0–39.7		
Temporal arterial scan thermometer	37.1	35.6–39.8		
	Nurse	Parent	Child	
Subjective evaluation, child friendly†				
Rectal measurement	2 (0–5)	2 (0–5)	2 (0–5)	
Tympanic thermometer	1 (0–3)	1 (0–5)	1 (0–5)	
Infrared skin scan thermometer	1 (0–5)	1 (0–5)	1 (0–5)	
Temporal arterial scan thermometer	1 (0–5)	1 (0–5)	1 (0–5)	
Subjective evaluation, ease of use‡				
Rectal measurement	3 (0–7)			
Tympanic thermometer	2 (0–6)			
Infrared skin scan thermometer	1 (0–9)			
Temporal arterial scan thermometer	2 (0–6)			

*Values are given in °C.

†Based on Likert score of 0–5. Values are given as median (range).

‡Based on visual analog scale score of 0–10. Values are given as median (range).

(tympanic scan $P < 0.0001$), 0.34°C (infrared skin scan $P < 0.0001$), and 0°C (temporal artery scan $P = 0.9288$), respectively.

Bland-Altman plots (Figures 1–3) confirm these mean differences and also illustrate the temperature-related influence on the magnitude and the direction of the difference between tympanic scan (Figure 1), infrared skin scan (Figure 2), and temporal artery scan (Figure 3), respectively, and the rectal reference value. All nonrectal measurement techniques resulted in a relatively higher result in the setting of a lower rectal body temperature ($< 37^{\circ}\text{C}$), and a relatively lower result in the setting of a higher rectal body temperature ($> 37.5^{\circ}\text{C}$). Thirty-three children showed a rectal body temperature above 37.8°C , of whom 22 had a body temperature above 38°C . Sensitivity, specificity, positive predictive value, and negative predictive value of the other measurement techniques compared with rectal measurement are provided in Table II.

Table I also provides data on the subjective impression on the child's comfort as assessed by nurse, parent, and child (Likert scale score) and the ease of use by the nurse (VAS score). Overall, there was good agreement between the different assessors, with a limited difference (median 2 vs median 1) between rectal measurement and the other techniques. Similar trends in differences were observed for ease of use as evaluated by the nurse.

Discussion

In a heterogeneous cohort of 294 children, we documented that the mean difference between tympanic scan, infrared skin scan, and temporal artery scan compared with rectal measurement was 0.49°C , 0.34°C , and 0°C , respectively. Compared with the rectal measurement device, all assessed tools overestimated body temperature at lower body temperature and underestimated at higher body temperature (Figures 1–3), resulting in sensitivity of 22% to 41% and a specificity of 98% to 100% for rectal temperature above 38°C .

A wide range of devices are available to exclude fever or to quantify body temperature in children. Although the multiplicity of modes and sites provides flexibility, it also introduces procedure or device-related variability. Such variability may be of clinical relevance (eg, predictive value to document the presence or

absence of fever)¹ or of pharmacodynamic relevance (eg, concentration time profile of acetaminophen for fever reduction).^{3,18} Based on our observations, none of the nonrectal measurement tools performed equal to the reference technique, although temporal artery scan was closest to this reference technique.

Our supportive findings in favor of temporal artery scan as second best confirms earlier observations in cohorts reported by Reynolds et al,¹⁶ Batra et al,⁷ Eyalade et al,⁹ and Bahorski et al.¹⁷ In essence, Reynolds et al¹⁶ concluded that mean (SD) temporal artery scan measurement (-0.46°C [0.5°C]), but not axillary (-0.93°C [0.49°C]) was sufficiently accurate when compared with rectal measurement in a cohort of 52 children.¹⁶ Unfortunately, this was only based on correlation studies; Bland-Altman analysis is obviously more appropriate to compare these measurements.¹⁶ More recently, Batra et al⁷ documented a similar mean difference and similar trends in differences in body temperature readings when rectal measurements were compared with either tympanic scan (0.5 ; 95% CI, -0.24°C to 1.37°C) or temporal artery scan measurement (0 ; 95% CI, -0.36°C to 0.3°C) in 100 children. There was a similar trend with an overestimation of noninvasive measurements in the setting of lower rectal temperature, and an underestimation in the setting of higher rectal temperature.⁷ In the Batra study,⁷ sensitivity and specificity for a rectal temperature above 38°C were 98% and 98% or 80% and 98% for tympanic scan and temporal artery scan thermometer measurement, respectively.⁷ Eyalade et al⁹ confirmed the same Bland-Altman pattern in 36 pediatric patients during general anesthesia: higher in the setting of low temperature and lower in the setting of high temperature before and during (30 and 60 minutes) anesthesia and mean differences of 0.29°C , 0.29°C , and 0.31°C when compared with rectal measurements.⁹ Finally, Bahorski et al¹⁷ reported on differences in rectal measurement versus temporal artery scan method in 47 pediatric patients and described a good correlation (0.86) and no significant difference between both measurements. Unfortunately, only correlations were reported and no Bland-Altman analysis had been performed.¹⁷ However, in patients with fever ($> 38^{\circ}\text{C}$; $n = 22$), temporal artery scan readings were lower in 18 out of 22 patients when compared with rectal measurement, confirming our observations on the affect of body temperature on the extent and direction of the difference (Figure 3).¹⁷

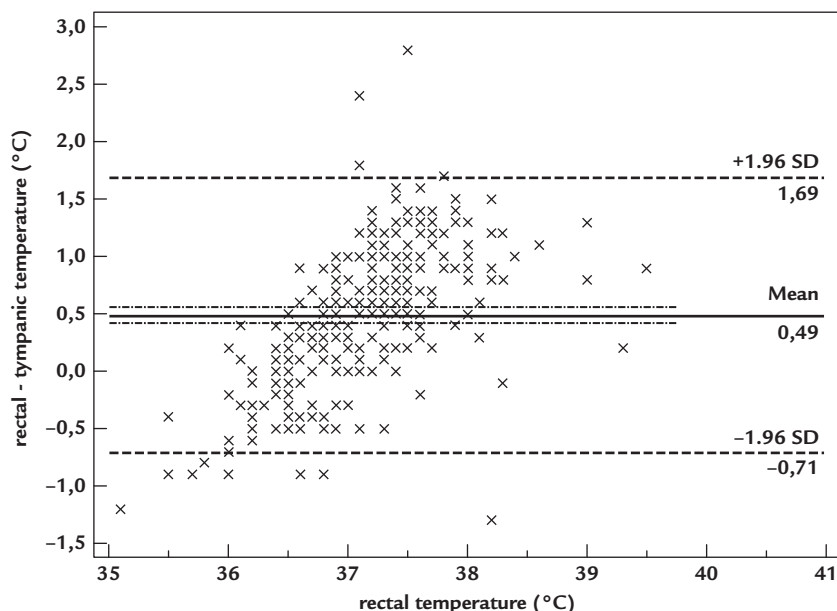


Figure 1. Bland-Altman plot illustrating a mean difference of 0.49°C , with a temperature-related influence on the direction and extent of the difference between rectal or tympanic scan temperature measurement.

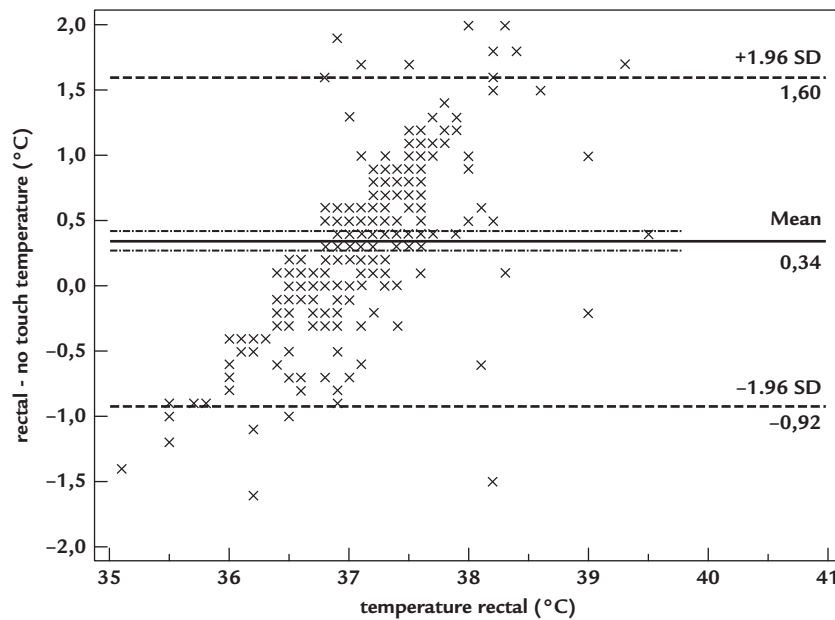


Figure 2. Bland-Altman plot illustrating a mean difference of 0.34°C, with a temperature-related influence on the direction and extent of the difference between rectal or infrared skin scan temperature measurement.

The underperformance of tympanic or infrared skin scan thermometers also confirms previous studies.^{6,8,13} In a recent meta-analysis by Dodd et al,⁸ the pooled estimates of sensitivity and specificity for tympanic scan thermometry were 63.7% (95% CI, 55.6%–71.8%) and 95.2% (95% CI, 93.5%–96.9%) for the diagnosis of fever (ie, 38°C) when compared with rectal temperature measurement. This means that tympanic scan thermometry would fail to diagnose fever in about one-third of cases.⁸ Paes et al⁶ conducted a similar study (rectal reference, tympanic and infrared skin, but no temporal artery scan thermometer in children). Based on observations in 100 children, similar differences (−0.27°C, 95% CI, −1.5°C to 1.05°C) of tympanic or infrared (Thermofocus, Varese, Italy) (−0.26°C, 95% CI, −1.75°C to 1.65°C) scan were documented.⁶ Sensitivity, specificity, positive predictive value, and negative predictive value for rectal fever (38°C) were 80%, 97%, 91%, and 94% for tympanic and 64%, 96%, 84%, and 89% for an infrared method.⁶

Finally, Selent et al¹³ compared 3 different infrared thermal skin detection systems (OptoTherm Thermoscreen, Sewickley, PA; FLIR ThermoVision 360, Boston, MA; and Thermofocus), and documented that sensitivity (compared with 38°C rectal) was between 77% and 84%; specificity was between 79% and 86%.

Although the number of studies that simultaneously compared different available assessment tools in a heterogeneous group of pediatric populations is limited, there were paired or specific subpopulation studies to compare with. In contrast, we were unable to retrieve data on how nurses, parents, and children evaluated these techniques. We found some differences between the different techniques, but the extent of these differences was overall more limited than initially anticipated, irrespective of who evaluated the intervention. Obviously, our study has its limitations. We a priori decided not to include axillary temperature measurement because there was already meta-analytical evidence on the differences when

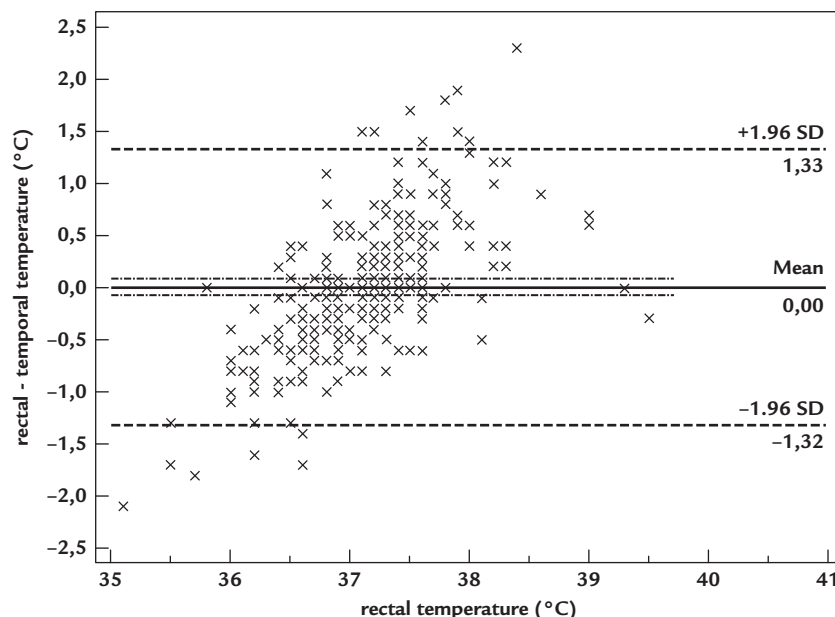


Figure 3. Bland-Altman plot illustrating a mean difference of 0°C, with a temperature-related influence on the direction and extent of the difference between rectal or temporal artery scan temperature measurement.

Table II

Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of raised body temperature of thermometer types when compared with rectal measurement as reference.

Body temperature	Tympanic thermometer	Infrared skin scan thermometer	Temporal artery scan thermometer
Cut off value 37.8°C (n = 33/294)			
Sensitivity	18	18	34
Specificity	99.6	99.5	94
PPV	86	86	42
NPV	90	91	92
Cut off value 38°C (n = 22/294)			
Sensitivity	22	27	41
Specificity	100	100	98
PPV	100	100	60
NPV	94	92	96

* Values are given as %.

compared with rectal measurement.⁵ Secondly, the overall number of patients—although quite high when compared with other reported cohorts—could have been higher, or additional recruitment of cases with either fever (38°C)¹⁶ or hypothermia⁹ likely is of benefit to draw additional or firmer conclusions. Finally, the study design aimed to reflect a real-life assessment. This means that measurements were not limited to study nurses only but were performed by the clinical nurses, there was only 1 temperature reading for each device, and all temperature readings were collected at 1 time point with an aimed time interval of < 5 minutes. Harmonization was aimed for based on formal training and verified based on intermittent compliance monitoring.

Taking these limitations into account, we documented that the mean difference between tympanic scan, infrared skin scan, and temporal artery scan compared with rectal measurement was 0.49°C, 0.34°C, and 0°C, respectively. All tools overestimated the temperature at lower and underestimated at higher body temperature, resulting in sensitivity of 22% to 41% and a specificity of 98% to 100% for rectal temperature above 38°C. This means that care providers should be aware of the limitations of nonrectal temperature measurement not yet reflected in the specific UK National Institute for Health and Care Excellence guideline on feverish illness in children.^{1,19} In a screening setting, sensitivity should be higher, whereas in a setting of consecutive measurement (eg, concentration-effect profiles as part of a pharmacologic study), the absolute values and the accuracy of the data will strongly depend on the tool applied. In our hands and based on our population, it seems that temporal artery scan measurement is second best but not optimal when compared with rectal measurement.

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Conflicts of Interest

The authors have indicated that they have no conflicts of interest regarding the content of this article.

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