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What is the Difference Between the Different Types of Thermometers?

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What is already known/ What this study adds

- *Rapid, practical, and non-invasive methods of measuring body temperature that provide measurements close to the core temperature have been developed. However, there is no widely accepted method that can reflect the core temperature exactly.*
- *The non-contact cutaneous thermometer (NCCT) and tympanic thermometer (TT) provided lower body temperature results than the oral measurement, while the temporal artery thermometer (TAT) measured body temperatures higher than the oral thermometer.*
- *If the fever cut-off value is taken as 37.4°C for NCCT, 37.7°C for TT, and 38°C for TAT, fever assessment can be made more accurately.*

ABSTRACT

Objective: There is no widely accepted method that can reflect the core temperature exactly. The aim of this study is to investigate the accuracy of frequently used body temperature measurement methods.

Materials and Methods: A total of 104 patients aged 3-9 years were included in this cross-sectional study. The body temperature was measured using a non-contact cutaneous thermometer (NCCT), tympanic thermometer (TT), temporal artery thermometer (TAT), and electronic oral thermometer. Four consecutive measurements each with a different technique were taken from each patient. The oral thermometer was accepted as the reference body temperature measurement method and an oral body temperature measurement of ≥37.8°C was accepted as fever.

Results: The NCCT and TT provided lower body temperature results than the oral measurement, while the TAT measured body temperatures higher than the oral thermometer. In patients whose temperature was measured as <37.8°C orally, the oral and TT measurements showed a strong positive association, while the other methods showed a weak positive association with the oral thermometer. In patients with fever, the oral and TT, and the oral and NCCT had a strong positive association while the oral thermometer and TAT had a moderate positive association. The result provided by the ROC analysis that was performed to determine the fever cut-off value for NCCT was 37.4°C, 37.7°C for TT, and 38°C for TAT.

Conclusion: None of the peripheral measurement methods can accurately measure the core temperature. However, the results can be interpreted more accurately if the characteristics of the thermometers are well known.

Keywords: Axilla, fever, forehead, oral, temporal artery

INTRODUCTION

Fever is one of the most common complaints in the pediatric outpatient clinics and emergency departments. Accurate measurement of body temperature prevents unnecessary examination of the patient and the possibility of overlooking the presence of fever. The aim of measuring body temperature is to obtain the most accurate reading of core temperature, which is the temperature of the internal organs in the head and trunk. As body temperature is regulated in the hypothalamus, the gold standard method of measuring core temperature is to measure the temperature of this region. The intracardiac and pulmonary artery blood temperatures or the esophageal temperature are also good indicators of core body core temperature but the temperature of these areas cannot be measured without highly invasive procedures.[1]

Rapid, practical, and non-invasive methods of measuring body temperature that provide measurements close to the core temperature have been developed. However, there is no

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widely accepted method that can reflect the core temperature exactly. The method that provides values closest to the core temperature is rectal thermometry.[2] Rectal temperature is the least variable method of temperature measurement under different environmental conditions. However, due to the urgency of the patient's condition in the emergency room, the patient's restlessness or lack of cooperation in pediatric patients, some relative contraindications (such as anal fissure), the increased time required to undress the patient, practicality, and privacy, rectal measurement has rarely been preferred in daily practice.[3] Oral thermometry can similarly provide values close to the pulmonary artery blood temperature.[4]

As regards other methods of temperature measurement, the tympanic membrane is perfused by an artery that also supplies the thermoregulation center of the body, making it an ideal site for measuring body temperature.[5] The temporal artery thermometer (TAT) measures the temperature by using infrared technology to detect heat naturally radiating from the skin surface of the forehead via the temporal artery. This method incorporates a patented arterial heat balance system that automatically accounts for the effects of ambient temperature on the skin. The non-contact cutaneous thermometer (NCCT) is the easiest to use and the least uncomfortable body temperature measurement method.

The aim of this study was to evaluate the accuracy and reliability of commonly utilized body temperature measurement methods—specifically tympanic, non-contact cutaneous, and TATs—in children aged 3-9 years. By comparing these methods, we sought to identify any variations in measurement precision across different devices, considering both practical implications and clinical reliability in pediatric healthcare settings.

MATERIALS AND METHODS

Study Participants

This cross-sectional study was conducted in the outpatient clinics of Children's Hospital, Ankara Bilkent City Hospital, between May 2022 and June 2022. Children aged 3-9 years were recruited randomly by the researchers. Before the body temperature measurement procedure, the patient's history was taken, and a physical examination was performed. Patients who presented with earache and/or otitis on physical examination, children with anomalies in the area where the body temperature was to be measured (such as deformities in the ear, cleft palate or lip, nevus on the skin), children with a stuffy nose and mouth breathing, patients with oral wounds, mucositis, gingivitis, or stomatitis; and patients who were tachypneic were not included in the study. Patients without these findings were included in the study. The participants were asked whether they had eaten or drunk anything in the previous half hour, and those who had were excluded. A total of 104 patients aged 3-9 years were included in the study. The age and sex of the participants were recorded.

The Body Temperature Measurement Methods

The temperature in the measurement rooms was between 22.5°C and 24°C. The oral thermometer was accepted as the reference body temperature measurement method and an oral body temperature measurement of ≥37.8°C was accepted as fever.[6] All measurements were performed by a single physician. The calibration of the thermometers was performed by the researcher according to the manufacturer's instructions as stated in the device's user manual. Measurements were taken at least half an hour after the patient entered the hospital. The body temperature was measured using a NCCT, tympanic thermometer (TT), temporal artery thermometer (TAT), and electronic oral thermometer. Four consecutive measurements each with a different technique were taken from each patient. The oral measurement was taken first, and the TT, NCCT, and TAT measurements were then taken in random order.

An electronic thermometer (Welch Allyn SureTemp Plus 690) with an oral measurement probe was used for the oral temperature measurement. After placing a probe cap on the thermometer probe, the probe was placed under the tongue and held until the temperature value appeared on the monitor. Temperature measurement with a TAT (TAT2000C/SmartGlow, Exergen Co.) was performed by placing the thermometer in the middle of the forehead, dragging it while following the temporal artery route up to the front of the tragus, and then gently dragging it to behind the ear without lifting. The value displayed on the screen when the finger was removed from the trigger was recorded as the measurement result. The skin temperature was measured using a non-contact infrared cutaneous thermometer (XS IFT-002B, Ganzhou Xianshun), holding the device at a distance of 5 cm to the middle of the forehead. The tympanic temperature was measured with an infrared TT (Thermoscan 3 IRT 3030, Braun) (Supplementary Figure 1). Otitis was excluded by otoscopic examination before the measurements. The measurement was taken from the left ear if the right ear was obstructed with earwax. With the patient in the sitting position, the auricle was pulled slightly upwards and backwards, and the probe of the TT was placed so that it completely covered the outer third of the outer ear canal before taking the measurement.

Local ethics committee approval was received for this study (Approval number: E2-22-1802) on May 11, 2022.

Statistical Analysis

Using the G*Power 3.1.9.4 software, sample size and power analysis were conducted based on the study by Hamilton et al,[7] with an effect size calculated at 0.29 (considering the mean difference of 0.17 ± 0.58 between the reference measurement and the TAT in the dependent group). Accepting a type 1 error of no more than 5% and a type 2 error of no more than 20%, a minimum of 94 patients would need to be included. It was planned to include at least 104 patients, considering a data loss rate of 10% during the trial. Data analysis was performed using The Statistical Package for the Social Sciences version 25.0 for Windows (IBM Corp.; Armonk, NY, USA). The Kolmogorov–Smirnov and Shapiro–Wilk tests were used to analyze the compliance of the variables with a normal distribution. Normally distributed data are presented as mean and standard deviation, and non-normally distributed data are presented as median and interquartile range (IQR). The Wilcoxon test is used in comparisons between 2 dependent groups in continuous numerical data that do not show normal distribution, and the Spearman correlation test is used to evaluate the correlations of continuous numerical data that do not show normal distribution. The strength of the Spearman correlation is determined

as follows: weak: 0.00-0.49, moderate: 0.50-0.69, strong: 0.70-1.00.[8]

The significance of the difference between the median values of the oral thermometer measurement and the other methods was evaluated using the Wilcoxon test. Spearman's rho test was used to evaluate the correlation between the values of the different thermometers, while Bland–Altman plots were used to evaluate the agreement between the oral thermometer and the other thermometers. In the Bland–Altman plots, the central horizontal line shows the median of the differences, while the upper and lower lines show the ±1.96 standard deviation values. Receiver operating characteristics (ROC) analysis was performed to determine fever cut-off values for NCCT, TT, and TAT, followed by calculating the sensitivity, specificity, positive predictive value, and negative predictive value (NPV) for these cut-off values. The area under the curve was calculated to assess the test's accuracy, with statistical significance considered at a type-1 error level of 5% or below. Cut-off values were determined using Youden index.[9]

RESULTS

Body temperature was measured in the 104 patients, consisting of 57 (54.8%) female and 47 (45.2%) male. The median age was 5 (4-7) years. Thirty-six (34.6%) of the participants were febrile (oral temperature ≥37.8°C). The median (IQR) values of the oral, NCCT, TT, and TAT measurements and the differences between oral measurements and those of the other thermometers are shown in Table 1. The box plots of each measurement are shown in Figure 1.

Correlation analysis with all measurements considered revealed a strong positive association of the methods with each other. In patients whose temperature was measured as <37.8°C orally, the oral and TT measurements showed a strong positive association, while the other methods showed a weak positive association with the oral thermometer. When the correlation was analyzed in patients with fever (oral temperature ≥37.8°C), the oral and TT, and the oral and NCCT had a strong positive association while the oral thermometer and TAT had a moderate positive association (Table 2). The Bland–Altman plots in Figure 2 show the mean difference and the upper and lower limits of the 95% CI for the mean difference between the oral and NCCT, oral and tympanic, and oral and TA thermometers.

The result provided by the ROC analysis that was performed to determine the fever cut-off value for NCCT was 37.4°C, with a sensitivity of 63.9%, specificity of 100%, PPV of 100%, and NPV of 84%. Similarly, using ROC analysis for the fever cut-off value for TT provided the ideal value as 37.7°C, with a sensitivity of 83.3%, specificity of 98.5%, PPV of 96.8%, and NPV of 91.8%. For TAT, the ideal fever cut-off value was 38°C, with a sensitivity of 91.7%, specificity of 97.1%, PPV of 94.3%, and NPV of 95.7% (Supplementary Figures 2-4).

Table 1. Body Temperature Measurement Results with Oral, Non-contact Cutaneous, Tympanic, and Temporal Artery Thermometers, and the Difference Between Oral Thermometers and the Other Thermometers

	Median (IQR), °C	*P*
Oral	36.9 (36.7-38)	
NCTT	36.7 (36.5-37.3)	
TT	36.8 (36.7-37.7)	
TAT	37.3 (36.8-38.3)	
Oral–NCCT difference	0.4 (0.2-0.7)	<.001
Oral–TT difference	0.1 (0-0.2)	<.001
Oral–TAT difference	−0.2 (−0.5-0)	<.001

IQR, interquartile range.
*Wilcoxon test.

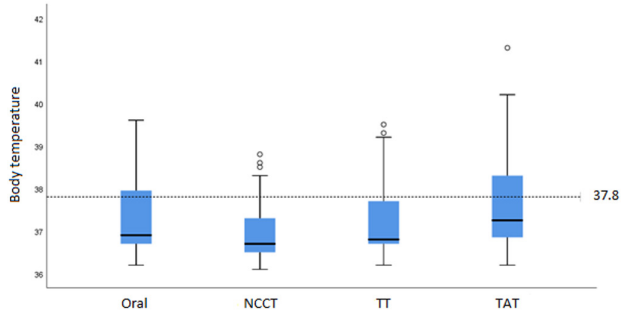

Figure 1. Box plot showing minimum, maximum, median, first quartile, and third quartile temperatures of each thermometer.

DISCUSSION

The NCCT and TT provided lower body temperature results than the oral measurement, while the TAT measured body temperatures higher than the oral thermometer. The smallest difference with the oral thermometer was provided by TT, and it also had the highest correlation with the oral thermometer. The correlation of the other thermometers with the oral thermometer showed a difference in patients with and without fever. In patients without fever, the oral and TT measurements showed a strong positive association, while the other methods showed a weak positive association with the oral thermometer.

Table 2. The Correlation Between the Oral, Non-Contact Cutaneous, Tympanic, and Temporal Artery Thermometers

		Oral	NCCT	TT	<37.8°C	Oral	NCCT	TT	≥37.8°C	Oral	NCCT	TT
NCCT	Rho	0.834			NCCT	0.453			NCCT	0.738		
	P	**<.001**				**<.001**				**<.001**		
TT	Rho	0.914	0.792		TT	0.702	0.315		TT	0.904	0.663	
	P	**<.001**	**<.001**			**<.001**	.009			**<.001**	**<.001**	
TAT	Rho	0.813	0.809	0.797	TAT	0.385	0.448	0.336	TAT	0.617	0.383	0.562
	P	**<.001**	**<.001**	**<.001**		**.001**	**<.001**	.005		**<.001**	**.021**	**<.001**

*Spearman correlation analysis.

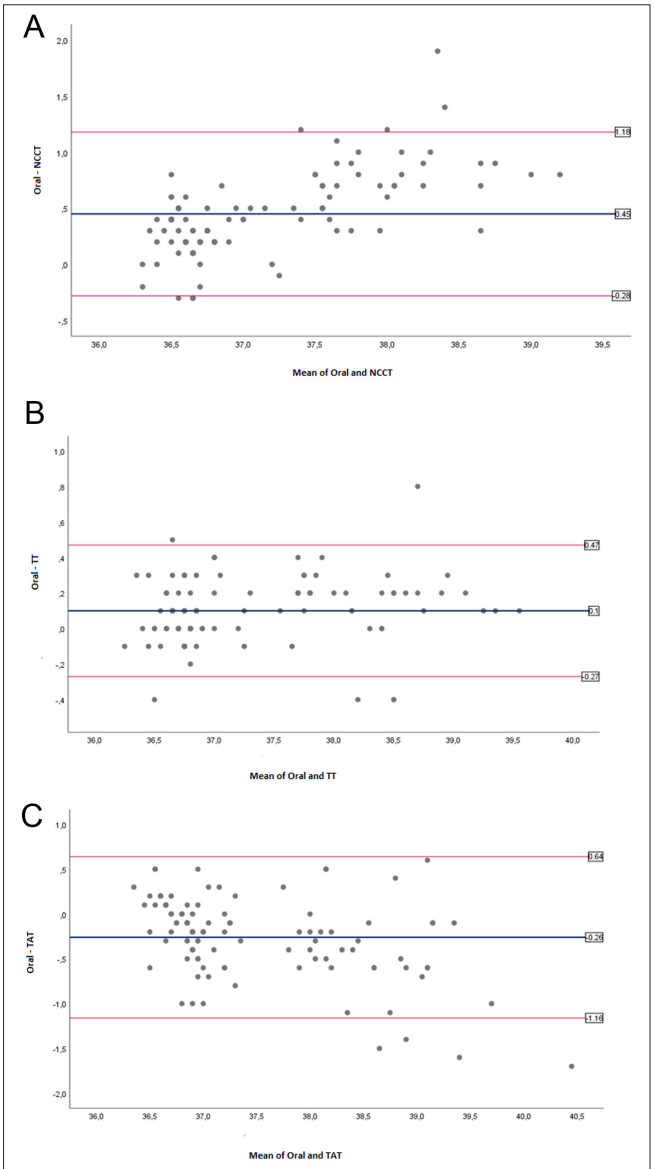

Figure 2. Bland–Altman plot with the median difference and 95% limits of agreement; (A) oral and non-contact cutaneous thermometers, (B) oral and tympanic thermometers, (C) oral and temporal artery thermometers.

In patients with fever, TT and NCCT showed a strong positive association, while TAT had a moderate positive association with the oral thermometer.

Tympanic thermometer has been reported to underestimate the core temperature in febrile patients, and to measure the body temperature higher than NCCT, with a statistically significant difference.[4,10] In line with these data, in the current study, TT provided body temperature values that were higher than NCCT but lower than the reference thermometer. In a meta-analysis of the diagnostic accuracy of TT at different fever thresholds in children, the optimal fever threshold was found to be 37.8°C with a sensitivity of 91%.[11] A study of children aged 6 months to 6 years found the TT to have a sensitivity of 95% and a PPV of 83% at a cut-off value for fever of 37.8°C.[12] In a large study involving 1364 patients with a median age of 72 months, the fever cut-off value for TT was also found to be 37.8°C.[13] The current study recommends a fever cut-off value of 37.7°C for TT. This cut-off value has high diagnostic power with high sensitivity, specificity, PPV, and NPD value and is close to the previously reported recommended cut-off values in the literature.

In a meta-analysis comparing tympanic and rectal thermometry in 5448 children, the mean difference between the results of a TT and rectal thermometer was 0.22°C (95% CI −0.44°C to 1.30°C), and the pooled mean difference between the tympanic and rectal temperature in the group of febrile children (rectal temperature >38°C) was 0.15°C (95% CI −0.32°C to 1.10°C). As this mean difference was high and the 95% CI was wide, the accuracy of the tympanic measurement was found to be poor, and it was suggested that it may not reflect the rectal measurement well.[14] In the current study, we found a mean difference of 0.1°C between the oral thermometer and TT. The Bland–Altman plot showed limits of agreement between −0.27°C and +0.47°C, which is not a wide range. A wider range of agreement was found in the Bland–Altman plots of the NCCT and TAT.

In a study of 294 children with a mean age of 3.2 years, TT, NCCT, and TAT were compared with the rectal thermometer as the reference measurement, and the mean difference was 0.49°C, 0.34°C, and 0°C, respectively. In the Bland–Altman plots, all thermometers measured body temperature higher than the reference thermometer when the body temperature was low (<37°C), and lower than the reference thermometer when the body temperature was high (>37.5°C).[15] In the current study, TT showed the smallest difference from the reference thermometer measurements. In the Bland–Altman plots, TT and NCCT generally measured body temperature lower than the oral thermometer in both febrile and afebrile children, while TAT typically measured higher. However, these differences may be due to the difference between the reference thermometer used in this study and the one used in the current study. Also the age group in the current study was older. In younger children, the external auditory canal is more curved and narrower, which may reduce the reliability of TT. The higher median age in the current study may have contributed to better results with TT due to improved usability in an older age group.

The correlation of all the thermometers with the reference thermometer was generally better in the presence of fever than in the absence of fever. Specifically, TT consistently showed a strong correlation with the oral thermometer in both febrile and afebrile conditions. However, NCCT exhibited a weak correlation in afebrile patients and a strong correlation in febrile patients. TAT displayed a weak correlation in afebrile patients and a moderate correlation in febrile patients. Thus, an improvement in the correlation with oral measurements was observed for both NCCT and TAT in febrile patients. This data should be interpreted with caution, as examination of the Bland–Altman graphs in the study revealed that the difference between the median values of the measurement methods widened as the mean body temperature increased. This widening difference suggests potential bias, indicating that higher body temperatures may amplify variability among measurement methods. Thus, although correlation coefficients suggest improved alignment in febrile states, the Bland–Altman

findings highlight a potential systematic difference at higher temperatures that could influence clinical interpretations.

It has been suggested that TAT overestimates the core temperature. Only 2 of the 33 patients with hypothermia detected by oesophageal monitoring under general anesthesia were confirmed to be hypothermic by TAT, whereas 31 patients with hypothermia detected by oesophageal thermometry were found to be normothermic by TAT. The difference between the reference thermometer and TAT was reported to be 0.67°C.[16] Similarly, the TAT measured a higher body temperature than the reference thermometer in the current study. The lower limit of agreement between the oral thermometer and the TAT was also much wider in the Bland–Altman plots. Data from the literature and the current study suggest that the TAT overestimates core temperature. Overestimation of core temperature may lead to a missed diagnosis of hypothermia or the misidentification of afebrile patients as febrile. Such inaccuracies may cause unnecessary concerns and additional investigations.

It is well documented that the forehead skin temperature, as measured with an infrared thermometer, is significantly affected by the ambient temperature. A study investigating the effect of changes in the external environmental temperature on the forehead, axillary, and oral temperatures has reported no significant changes in the axillary and oral temperatures, while the forehead skin temperature was significantly affected, for example, by increasing when the ambient temperature increased. There was a significant difference between the forehead and oral temperature, and the forehead and axillary temperature when the ambient temperature was low (14°C-24°C) but no statistically significant difference when the ambient temperature was increased (at temperatures of 28°C and 32°C). However, ambient temperatures >24°C and <28°C were not analyzed. The mean difference between the oral and forehead temperature was found to be 0.49°C, with the forehead temperature being lower.[17] The difference between the oral and forehead temperature was also very similar to this value in the present study. Considering that our study was conducted in an environment where the ambient temperature was between 22.5°C and 24°C, the forehead temperature would be expected to be significantly lower than the oral temperature. The ambient temperature should be taken into account when determining the fever cut-off value for NCCT. A fever cut-off of 37.4°C, as in the present study, seems appropriate when the ambient temperature is <24°C, but this cut-off may not be accurate when the ambient temperature is higher.

Although the results of the current study seem to support the use of TT, the important disadvantage of tympanic thermometry is that it is influenced by otological factors. It has been reported that acute otitis externa increases the TT reading by an average of 0.36°C and that earwax decreases the reading by 0.3-0.6°C.[18-20] The TT should be placed in the external auditory canal by gently pulling the auricle downwards and outwards in young children and upwards and outwards in older children so that the probe completely covers the external auditory canal. Application errors in these steps affect the reliability of the measurement. In a study comparing TT measurements by parents and nurses, the temperatures measured by the parents were found to be significantly different from those of the nurses. The fact that the nurses' measurements correlated much better with the body temperature obtained by the reference method suggested that the parents were not using the ideal technique.[21] These are limitations of TT that should not be underestimated. It is difficult to be convinced that parents can use a TT properly at home by following the correct steps. For this reason, TT is probably best used by experienced personnel in the hospital rather than at home. To improve the reliability of TT use in home settings, certain measures could be implemented. Manufacturers of TT devices could create instructional videos demonstrating the correct usage technique, and family physicians could provide training on proper TT usage during routine check-ups for families who report using this device. These educational supports may help reduce user error, promoting safer and more effective use of TT at home.

This study has several limitations. Firstly, it included children aged 3 to 9 years. While this age group provides valuable data, fever detection in younger children, particularly infants, poses unique challenges. Conducting further studies with a broader age range would yield more generalizable conclusions. Secondly, the small sample size is another limitation, with only one-third of cases identified as febrile. Increasing the sample size in future research could help validate these findings and establish more reliable cut-off values. Additionally, this study was conducted within a narrow ambient temperature range (22.5-24°C). Given the well-documented influence of ambient temperature on NCCTs, the findings cannot be generalized to settings with fluctuating temperatures. In environments where optimal temperature control is lacking, adjustments for ambient temperature are essential to ensure accurate NCCT readings. Intra-observer consistency and repeatability can be evaluated by taking multiple measurements from the same individual when a single observer performs all measurements. However, in this study, only one measurement was taken for each method, and therefore, the repeatability of measurements was not assessed. This represents another limitation of the study.

CONCLUSION

None of the peripheral measurement methods can accurately determine core temperature. However, results can be interpreted more reliably when the characteristics and limitations of each thermometer are well understood. Non-contact cutaneous thermometers underestimate and TA thermometers overestimate the body temperature. This can be overcome by using appropriate fever cut-off values. Although the TT seems to be the most reliable method, its limitations make it more appropriate for hospital settings than for use by families at home. For TTs, a cut-off value of 37.8°C is more reliable than 38°C, particularly for children aged 3-9 years, making it a highly suitable option for measuring body temperature in this age group.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Ethics Committee Approval: This study was approved by the Ethics Committee of Ankara Bilkent City Hospital (Approval no.:E2-22-1802, Date: May 11, 2022).

Informed Consent: Written informed consent was obtained from the patients/patient who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept –G.İ.B.; Design –G.İ.B., I.K.S.; Supervision – G.İ.B.; Resources – G.İ.B., I.K.S.; Materials – G.İ.B., I.K.S.; Data Collection and/or Processing – I.K.S.; Analysis and/or Interpretation – G.İ.B., I.K.S.; Literature Search –G.İ.B., I.K.S.; Writing – G.İ.B., I.K.S.; Critical Review – G.İ.B.

Declaration of Interests: The authors have no conflicts of interest to declare.

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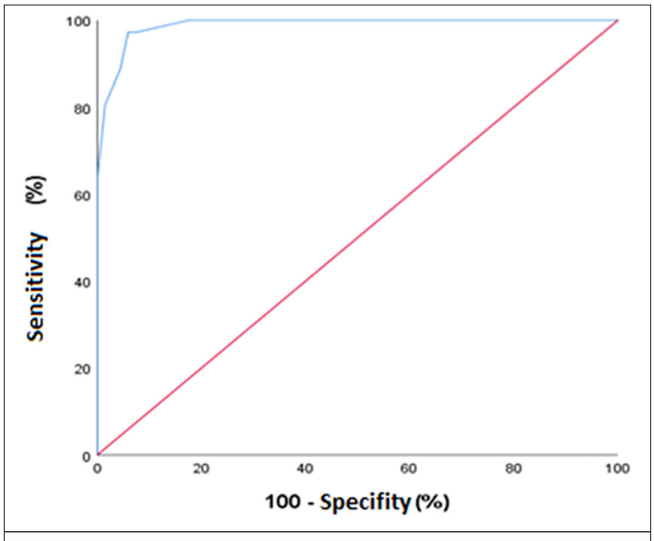
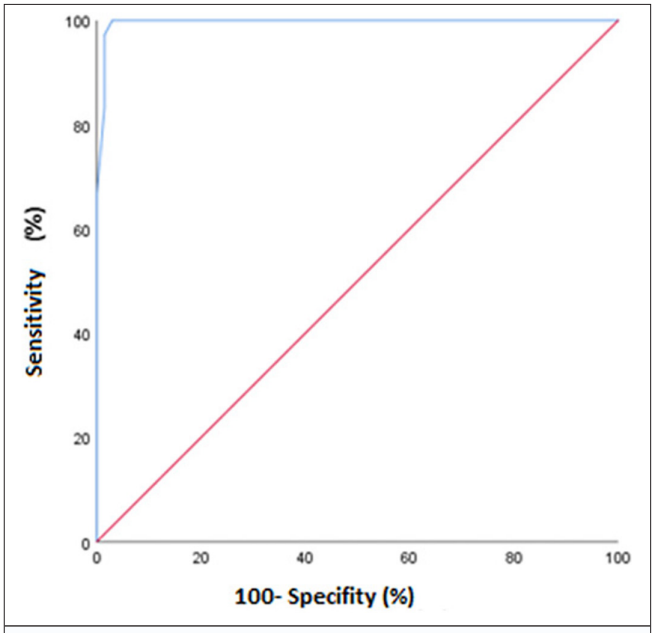
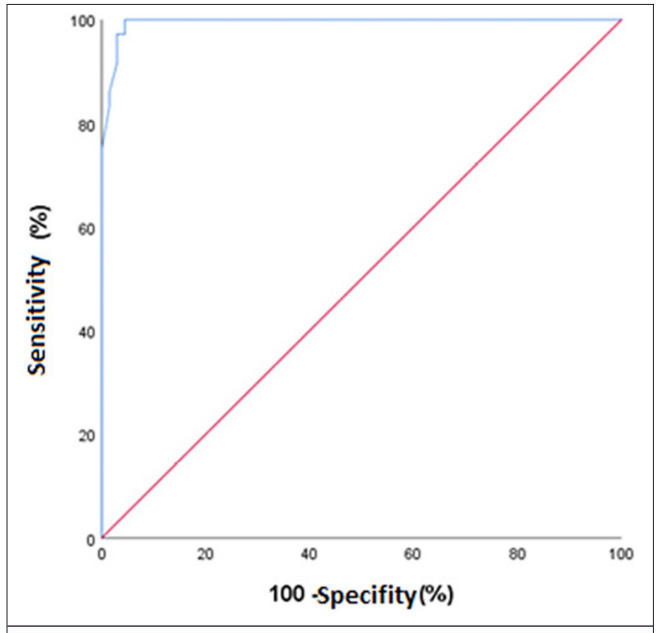
Supplementary Figure 1. Photographs of the thermometers used in the study. Thermometers used for oral, temporal artery, cutaneous, and tympanic measurements, from left to right.



Supplementary Figure 2. ROC curve for body temperature measurement with NCCT.



Supplementary Figure 3. ROC curve for body temperature measurement with tympanic thermometer.



Supplementary Figure 4. ROC curve for body temperature measurement with TAT.