A Comparative Study of 3 Different Methods of Temperature Measurement in Children

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Background: The accuracy of body temperature measurement is very important in children. The accuracy and reliability of the forehead skin thermometer (FST) and infrared tympanic thermometer (ITT) are inconclusive.

Objectives: To determine: 1) the mean difference, agreement, and accuracy of body temperature detected in children by FST and ITT, as compared with the gold standard rectal mercury-in-glass thermometer (RMT); and, 2) the cut-off level for FST and ITT in the detection of fever.

Material and Method: Children ≤2 years old with the chief complaint of “fever” were recruited for this study. Body temperature (BT) was measured by 3 different methods, including FST, 5 times; ITT, 3 times; and, RMT, 1 time, for each patient. Each measurement method was performed by 3 well-trained staff members, all of whom were blinded to the recorded data of the other methods. The mean difference in body temperature, agreement by Bland-Altman method, and the verified performance of FST and ITT by diagnostic test were assessed.

Results: A total 312 children were recruited. Body temperatures measured by FST and ITT were lower than those measured by RMT, with a mean difference of 1.04 °C (p<0.001) and 1.03 °C (p<0.001), respectively. In subgroup analysis by levels of fever, the mean differences between rectal temperature and both forehead and ear temperature were statistically significantly different (p<0.001) for all levels of fever. Regarding the diagnostic test to verify performance, the data revealed the most practical cut-off point to be 37.0 °C for both FST and ITT, as compared to the gold standard RMT.

Conclusion: Both FST and ITT were found to be accurate temperature screening methods for daily clinical use. However, the cut-off points to detect fever should be lowered to 37.0 °C to be consistent with gold standard measurement.

Keywords: Body temperature measurement, Forehead skin thermometer, Infrared tympanic thermometer, Rectal mercury-in-glass thermometer

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Accurate body temperature measurement is crucial in general pediatric practice. Incorrect diagnosis of fever in children can lead to improper case management and serious complications. Ideal body temperature measurement should be accurate, fast, pain-free, and easy to perform.

Body core temperature is the most accurate and reliable temperature measurement. Body core temperature can be measured at the pulmonary artery, lower esophagus, or rectum. Pulmonary artery and lower esophagus measurement are invasive and are, therefore, not practical for daily clinical practice. Among non-invasive methods, rectal temperature measurement is considered to be the gold standard for measurement of body core temperature. Parents and guardians, however, express reluctance to perform rectal temperature measurement at home.

Many methods of body temperature measurement, including oral temperature, axillary temperature, ear/tympanic membrane temperature, and forehead temperature, are used in daily practice. However, the studies focusing on the accuracy and reliability of each of these measurements have been inconclusive(1-17). In addition, the cut-off levels to define fever for ear temperature and forehead temperature have not been determined.

In response to this lack of definitive information, the authors compared the forehead skin thermometer (FST) and infrared tympanic thermometer (ITT) to the rectal mercury-in-glass thermometer (RMT), which is and has been regarded as the gold standard for temperature measurement in children. The authors
studied mean difference in body temperature, the agreement between methods, and the accuracy of each method. The cut-off levels to define fever for FST and ITT were also determined.

Material and Method

This comparative, cross-sectional study was approved by the Institutional Review Board (IRB), Faculty of Medicine, Chulalongkorn University and adheres to the provisions outlined in the Declaration of Helsinki (IRB No. 538/54).

Participants

Children, aged 0-2 years, who visited the pediatric outpatient clinic at King Chulalongkorn Memorial Hospital with the chief complaint of “fever” were recruited for this study. Children with unstable vital signs, rectal/ear/other anomalies, chief complaint of ear pain or ear discharge, perianal infection, diarrhea, low platelet count, diagnosis of otitis media, uncooperative children, and disapproving parents were excluded from the study. A procedure explanation and information sheet was provided to all parents/guardians before they were asked to sign the informed consent document.

Sample size was calculated by using the formula for two related groups to have a 90% chance of detecting a mean difference in temperature (SD) by 0.21 (0.42) at the 95% confidence level. A sample size of 100 subjects was required for each level of fever.

Level of fever was determined by rectal temperature, as follows: afebrile (<38.0 degrees celsius (°C)), low-grade fever (38.0-38.9°C), and high-grade fever (≥39.0°C)(18).

Validation of equipment and human measurers

The authors tested the accuracy and precision of equipment used in this study to decrease inter-equipment variation. Regarding the FST (Coolkids®, NanoMed, Thailand), 5 strips were simultaneously measured on the forehead of a person for 15-20 seconds or until the color of liquid crystal stopped changing(9). For forehead temperatures, measurement was performed 5 times to decrease measurement error. The temperature difference for each FST reading was 0.5°C. Accordingly, the mean difference value for 5 times would be 0.1°C, which correlated with the other measurement equipment that also has a minimal mean difference of 0.1°C. Ear temperature by ITT (Microlife IR1DE1-1®, Microlife AG, Switzerland) was performed by slightly pulling the pinna backward and upward, placing the probe into the external ear canal, pressing the button, and ending the measurement after hearing the “BEEP” sound in approximately 2-3 seconds(13). Ear temperature by ITT was performed three times and was then followed by rectal temperature measurement. RMT, coated with petroleum jelly, was gently placed into the rectum until the probe was no longer visible (around 2-3 cm) for 3 minutes(17). All of these measurement procedures were performed in the same environment.

Demographic data (age, sex, and underlying disease), diagnosis, and temperature measurements by all three temperature measurement methods were recorded.

Ethics consideration

The present study was approved by the Institutional Review Board (IRB), Faculty of Medicine, Chulalongkorn University and adheres to the provisions outlined in the Declaration of Helsinki (IRB No 538/54).

Statistical analysis

Categorical data are presented by number and percentage, while continuous data are expressed by mean ± SD. Mean values of FST and ITT were compared with rectal temperature using paired t-test, with \( p < 0.05 \) considered statistically significant. Statistical analysis was performed using SPSS version 17.0 (SPSS, Inc., Chicago, IL, USA). Agreement was assessed by Bland-Altman statistical method according to level of fever, with a difference not exceeding 0.2°C considered to be within clinically acceptable limits(9). The performance of FST and ITT were verified by diagnostic test. The cut-off level for fever was determined by ROC curve.
Results

Demographic data

A total of 312 children (M: F = 184:128) were enrolled in this study, with a mean age of 9.9 ± 5.9 months (10 days-24 months). The 312 children were divided into 3 groups according to level of fever, as follows: afebrile (109, 34.9%), low-grade fever (103, 33.0%), and high-grade fever (100, 32.1%).

Mean temperature from different methods

The mean (SD) value for rectal temperature was 38.39 (0.90)°C, while mean forehead temperature and ear temperature were 37.36 (0.90)°C and 37.37 (0.93)°C, respectively.

Mean difference and the agreement between rectal temperature and other sites, as assessed by Bland-Altman statistical method

The differences between rectal temperature and forehead and ear temperature were 1.04°C (95% CI -0.25-2.32) (Fig. 1) and 1.03°C (95% CI 0.06-1.99) (Fig. 2), respectively. This outcome demonstrated a relative lack of agreement between rectal temperature and both forehead and ear temperature.

Comparison of mean difference between rectal temperature and other sites, categorized by level of fever

When the results were sub-analyzed by level of fever, the mean differences between rectal temperature and both forehead and ear temperature were statistically significantly different (p<0.001) for all levels of fever (Table 1).

Performance of forehead skin thermometer and infrared tympanic thermometer and ROC curve analysis

Rectal temperature ≥38.0°C was set as the gold standard for the diagnosis of fever. Of 312 children, 203 children were diagnosed with having fever.

Area under the curve (AUC) by ROC curve of forehead and ear temperature were 0.906 (95% CI 0.873-0.939) and 0.951 (95% CI 0.929-0.973) with p<0.001, respectively.

The most appropriate cut-off point for diagnosing fever for each method was determined by choosing the most accurate value. For forehead temperature, 37.1°C was the most accurate cut-off; for ITT, 37.02°C was the most accurate point (Table 2).

For forehead temperature, when setting the temperature cut-off point at ≥38.0°C to diagnose fever, the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) for forehead temperature were 48.3%, 100%, 100%, and 51.2%, respectively.

For ear temperature, when choosing a cut-off point ≥37.6°C (the temperature set by the manufacturer to detect fever), sensitivity, specificity, PPV, and NPV were 62.1%, 99.1%, 99.2%, and 58.6%, respectively.

When applying the new cut-off point from ROC analysis for forehead temperature (37.0°C), sensitivity, specificity, PPV, and NPV were 90.1%, 56.0%, 79.2%, and 75.3%, respectively (Table 3). For ear temperature (37.0°C), sensitivity, specificity, PPV, and NPV were 89.2%, 84.4%, 91.4%, and 80.7% respectively (Table 4).

Discussion

This study endeavored to determine the mean
The data showed that there was a statistically significant difference between rectal temperature and both forehead and ear temperature. These results are consistent with other studies reporting that forehead temperature differed from rectal temperature in children. The cut-off levels to define fever for FST and ITT were also determined.

Table 2. Calculation of the cut-off point from ROC curve for forehead skin thermometer (FST) and infrared tympanic thermometer (ITT)

<table>
<thead>
<tr>
<th>Test result variables</th>
<th>Value</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forehead temperature</td>
<td>36.90</td>
<td>90.1</td>
<td>56.4</td>
<td>79.2</td>
<td>75.6</td>
<td>78.3</td>
</tr>
<tr>
<td></td>
<td>37.10</td>
<td>80.8</td>
<td>95.5</td>
<td>97.0</td>
<td>72.9</td>
<td>85.9</td>
</tr>
<tr>
<td></td>
<td>37.30</td>
<td>73.4</td>
<td>97.3</td>
<td>98.0</td>
<td>66.5</td>
<td>81.8</td>
</tr>
<tr>
<td></td>
<td>37.90</td>
<td>48.3</td>
<td>100</td>
<td>100</td>
<td>51.2</td>
<td>66.5</td>
</tr>
<tr>
<td></td>
<td>38.10</td>
<td>24.1</td>
<td>100</td>
<td>100</td>
<td>41.7</td>
<td>50.8</td>
</tr>
<tr>
<td>Ear temperature</td>
<td>36.92</td>
<td>90.6</td>
<td>83.6</td>
<td>91.1</td>
<td>82.9</td>
<td>88.2</td>
</tr>
<tr>
<td></td>
<td>37.02</td>
<td>88.7</td>
<td>91.8</td>
<td>95.2</td>
<td>81.5</td>
<td>89.8</td>
</tr>
<tr>
<td></td>
<td>37.05</td>
<td>86.7</td>
<td>92.7</td>
<td>95.7</td>
<td>79.1</td>
<td>88.8</td>
</tr>
<tr>
<td></td>
<td>37.98</td>
<td>41.9</td>
<td>100</td>
<td>100</td>
<td>48.2</td>
<td>62.3</td>
</tr>
<tr>
<td></td>
<td>38.02</td>
<td>41.4</td>
<td>100</td>
<td>100</td>
<td>48.0</td>
<td>62.0</td>
</tr>
</tbody>
</table>

PPV = positive predictive value, NPV = negative predictive value

For ear temperature, many studies support our finding that ear temperature differs at least 0.5°C from rectal temperature. Vanstaaij BK, in a study of only 41 children, reported that ear temperature accurately reflected rectal temperature. Similarly, Loveys AA noted that rectal and ear temperature measurements were not different.

In subgroup analysis by level of fever, the results illustrated that both forehead and ear temperature were significantly lower than rectal temperature at all levels of fever. This finding partially supports Brennan DF’s study finding that ITT is less sensitive in detecting high fever. Regarding FST, the authors hypothesize that peripheral vasoconstriction in high-grade fever may explain the added difference between forehead and rectal temperature.

When using standard cut-off values, both the FST and ITT thermometers had a lower ability to accurately detect fever. After using optimal diagnostic thresholds from the ROC curve (Table 2), performance was improved in terms of sensitivity, negative predictive

Table 1. Mean difference between rectal mercury-in-glass thermometer and other methods categorized by level of fever in subgroup analysis

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Rectum temperature (A) (SD)</th>
<th>Forehead temperature (B) (SD)</th>
<th>Ear temperature (C) (SD)</th>
<th>Difference (A-B) (SD)</th>
<th>Difference (A-C) (SD)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Afebrile</td>
<td>37.47±0.27</td>
<td>36.66±0.42</td>
<td>36.46±0.49</td>
<td>0.81±0.48</td>
<td>1.01±0.53</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td></td>
<td>Low-grade fever</td>
<td>38.29±0.25</td>
<td>37.38±0.66</td>
<td>37.37±0.49</td>
<td>0.91±0.59</td>
<td>0.91±0.46</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td></td>
<td>High-grade fever</td>
<td>39.51±0.42</td>
<td>38.15±0.61</td>
<td>38.36±0.58</td>
<td>1.36±0.56</td>
<td>1.16±0.45</td>
<td>&lt;0.001**</td>
</tr>
</tbody>
</table>

Results are presented as mean ± SD; p-value using paired t-test, (** p<0.01)
value, and accuracy. Ear temperature was moderately more consistent with rectal temperature than was forehead temperature. According to these findings, forehead and ear temperature can be confidently implemented as a screening measure in routine practice or at home. In cases of uncertain diagnosis, rectal temperature should be used as the gold standard. This application would effectively decrease the number of children who require the rectal temperature method for fever detection, decrease the amount of time invested in measuring rectal temperature, and reduce the possibility of injury from glass breakage and mercury poisoning.

The strengths of this study include larger
sample size than previous studies and lower potential for bias by blinding measurers to the results obtained by other measurement methods. The authors reduced measurement error as much as possible by testing and evaluating correlations relating to equipment, human measurers, increasing sample size, repeated measurement (for both FST and ITT), and choosing rectal temperature as the gold standard for fever detection. In addition, the authors assigned each of our 3 human measurers to only 1 measurement method for the duration of the study.

A notable limitation of this study is the acknowledgement that the brands of thermometers used (both FST and ITT) may not represent all brands available in the market.

In conclusion, both FST and ITT can be used in clinical practice and at home as a temperature screening measure, given their consistency with rectal temperature when the new cut-off value is assigned.

What is already known on this topic?
Accurate body temperature measurement is crucial in general pediatric practice. Among non-invasive methods, rectal temperature measurement is considered to be the gold standard but it is not comfortable for the guardians to perform it at home. Many methods of body temperature measurement, including forehead and ear temperature, are used in daily practice. However, the studies have reported conflicting data on the accuracy and reliability of each of these measurements. In addition, the cut-off levels to define fever for forehead and ear temperature have not been determined.

What this study adds?
Both forehead and ear temperature could be confidently implemented as a screening measure in routine practice or at home if the cut-off points to detect fever were lowered to 37.0°C to be consistent with gold standard measurement.

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Potential conflicts of interest
None.

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การศึกษาเปรียบเทียบการวัดอุณหภูมิของร่างกายในเด็กโดยวิธีที่แตกต่าง 3 แบบ

สุริยา ตันกรีนทร์, ภัณฑ์ เทมวัฒน์จัน, เทอดพงศ์ เดิมเกลย, ศรีวรรณ นามกุธ

วัตถุประสงค์: การวัดอุณหภูมิในเด็กอาจมีความแตกต่างในการวัดได้ โดยวิธีการวัดนั้นอาจมีความสอดคล้องหรือไม่ จึงมีการส่งเสริมการวัดอุณหภูมิที่แม่นยำเกี่ยวกับการวัดอุณหภูมิในเด็ก 2 แบบ คือ วัดอุณหภูมิที่หน้าอกจุดศูนย์กลางบริเวณอกและсмотретьที่ต้นสันหลัง

วิธีวิจัย: เป็นการศึกษาแบบเปรียบเทียบ จำนวนเด็ก 312 ราย วิเคราะห์ข้อมูลด้วยวิเคราะห์สถิติทางวิทยาการอิลลิเดอร์ วัดการวัดอุณหภูมิโดยการวัดที่หน้าอกจุดศูนย์กลางบริเวณอกและดูที่ต้นสันหลังใช้โปรแกรม SPSS ด้วยวิธีการวัดอุณหภูมิแบบที่หน้าอกจุดศูนย์กลางบริเวณอก

ผลการศึกษา: จำนวนเด็กที่มีผลการวัด อุณหภูมิที่หน้าอกจุดศูนย์กลางบริเวณอกและดูที่ต้นสันหลัง จำนวนเด็กที่มีผลการวัด อุณหภูมิที่หน้าอกจุดศูนย์กลางบริเวณอกและดูที่ต้นสันหลัง จำนวนเด็กที่มีผลการวัด อุณหภูมิที่หน้าอกจุดศูนย์กลางบริเวณอกและดูที่ต้นสันหลัง จำนวนเด็กที่มีผลการวัด อุณหภูมิที่หน้าอกจุดศูนย์กลางบริเวณอกและดูที่ต้นสันหลัง

ผลการวิเคราะห์: สรุปผลการวัดอุณหภูมิโดยการวัดที่หน้าอกจุดศูนย์กลางบริเวณอกและดูที่ต้นสันหลัง ซึ่งมีผลการวัดอุณหภูมิที่หน้าอกจุดศูนย์กลางบริเวณอกและดูที่ต้นสันหลัง