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*

J Med Assoc Thai 2016; 99 (2): 142-9
Full text. e-Journal: *http://www.jmatonline.com*

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

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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)[15] 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[8]. The strips that demonstrated the same results were chosen for use in this study. For the RMT, the temperature readings of 40 RMT were simultaneously measured in hot water for 3 minutes and the units with a variation of ±0.1°C were selected. Three human measurers were trained and assigned to measuring temperatures using only 1 type of equipment for the duration of the study. Each measurer was blinded to the recorded data of other methods to avoid bias.

Temperature measurement

Temperature measurement was taken 30-60 minutes after clinic arrival or at least 10 minutes after playing to avoid confounding factors, such as heat and perspiration. A forehead skin thermometer (FST) (Coolkids®, NanoMed, Thailand) was placed on the patient's dry forehead for 15-20 seconds or until the color of the liquid crystal stopped changing[8]. 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).

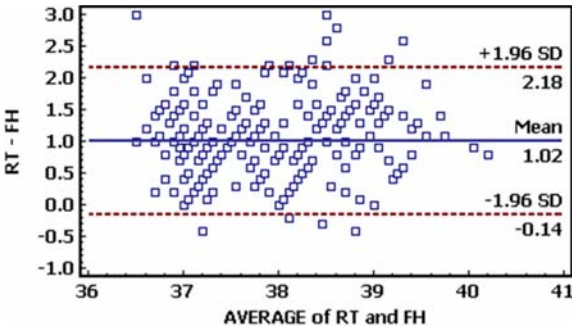
Performance of forehead skin thermometer and infrared tympanic thermometer and ROC curve analysis

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.

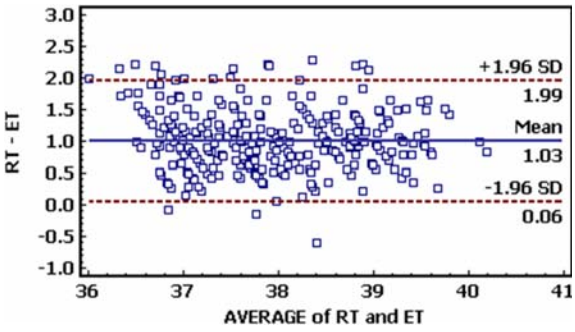
The most appropriate cut-off point for diagnosing fever for each method was determined by choosing the most accurate value. For forehead temperature, 37.1°C was the most accurate cut-off; for ITT, 37.02°C was the most accurate point (Table 2).

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.



RT = rectum temperature, FH = forehead temperature

Fig. 1 Bland-Altman plot representing the differences between rectal mercury-in-glass thermometer (RMT) and forehead skin thermometer (FST).



RT = rectum temperature, ET = ear temperature

Fig. 2 Bland-Altman plot representing the differences between rectal mercury-in-glass thermometer (RMT) and infrared tympanic thermometer (ITT).

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

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

	n	Rectum temperature (A) (SD)	Forehead temperature (B) (SD)	Ear temperature (C) (SD)	Difference (A-B) (SD)	Difference (A-C) (SD)	*p*-value	
							A vs. B	A vs. C
Afebrile	109	37.47±0.27	36.66±0.42	36.46±0.49	0.81±0.48	1.01±0.53	<0.001**	<0.001**
Low-grade fever	103	38.29±0.25	37.38±0.66	37.37±0.49	0.91±0.59	0.91±0.46	<0.001**	<0.001**
High-grade fever	100	39.51±0.42	38.15±0.61	38.36±0.58	1.36±0.56	1.16±0.45	<0.001**	<0.001**

Results are presented as mean ± SD; *p*-value using paired t-test, (**) $p<0.01$

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

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

PPV = positive predictive value, NPV = negative predictive value

difference, the agreement, and the accuracy of body temperature detected by FST and ITT, as compared with the gold standard rectal mercury-in-glass thermometer (RMT), according to level of fever in children. The cut-off levels to define fever for FST and ITT were also determined.

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[8,11,14,19]. However, the aforementioned findings contrast study findings reported by Muata L, who reported that forehead temperature could be used as a gold standard temperature, instead of axillary temperature by axillary mercury-in-glass thermometer (AMT)[12]. From our point of view, axillary temperature is not likely to indicate core body temperature as precisely as does rectal temperature.

For ear temperature, many studies support our finding that ear temperature differs at least 0.5°C from rectal temperature[5,8,11]. Vanstaaij BK, in a study of only 41 children, reported that ear temperature accurately reflected rectal temperature[16]. Similarly, Loveys AA noted that rectal and ear temperature measurements were not different[20].

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[5]. 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 3. Performance of forehead temperature with the new cut-off point from ROC analysis (37.0°C)

	Rectum		Total
	≥38°	<38°	
Forehead			
≥37°	183	48	231
<37°	20	61	81
Total	203	109	312
	Expected	[95% confidence interval]	
		Lower	Upper
Sensitivity	90.1%	85.2%	93.9%
Specificity	56.0%	46.1%	65.5%
Positive predictive value	79.2%	73.4%	84.3%
Negative predictive value	75.3%	64.5%	84.2%
ROC area	0.73	0.68	0.78
Kappa	0.49	0.39	0.59
Agreement	78.2%	73.2%	82.7%

Table 4. Performance of ear temperature with the new cut-off point from ROC analysis (37.0°C)

	Rectum		Total
	≥38°	<38°	
Ear temperature			
≥37°	181	17	198
<37°	22	92	114
Total	203	109	312
	Expected	[95% confidence interval]	
		Lower	Upper
Sensitivity	89.2%	84.1%	93.1%
Specificity	84.4%	76.2%	90.6%
Positive predictive value	91.4%	86.6%	94.9%
Negative predictive value	80.7%	72.3%	87.5%
ROC area	0.87	0.83	0.91
Kappa	0.73	0.65	0.81
Agreement	87.5%	83.3%	91.0%

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.

Acknowledgements

This study was supported by a grant from the Ratchadapisek Sompotch Endowment Fund, Chulalongkorn University. The authors would like to gratefully acknowledge the Chulalongkorn University research affairs team for advice and English editing of this manuscript.

Potential conflicts of interest

None.

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การศึกษาเปรียบเทียบการวัดอุณหภูมิของร่างกายในเด็กโดยวิธีที่แตกต่างกัน 3 แบบ

สุชีรา ฉัตรเพริดพราย, กนิษฐา เหมะวัฒนะชัย, เทอดพงศ์ เต็มภาคย์, ศิริวรรณ วนานุกูล

ภูมิหลัง: การวัดอุณหภูมิร่างกายในเด็กอย่างถูกต้องมีความสำคัญในเวชปฏิบัติ ผลการศึกษาที่ผ่านมาเกี่ยวกับการวัดอุณหภูมิร่างกาย โดยวิธีการใช้แผ่นวัดอุณหภูมิทางผิวหนัง บริเวณหน้าผากและการใช้เครื่องวัดอุณหภูมิชนิดดิจิตอลอินฟราเรดสำหรับวัดอุณหภูมิทางหู ยังสรุปผลความถูกต้องและความน่าเชื่อถือได้ไม่แน่นอน

วัตถุประสงค์: เพื่อศึกษา 1) ค่าเฉลี่ยความแตกต่าง (mean difference) ความสอดคล้อง (agreement) และความถูกต้องของการวัดอุณหภูมิร่างกายโดยวิธีการใช้แผ่นวัดอุณหภูมิทางผิวหนังบริเวณหน้าผากและการใช้เครื่องวัดอุณหภูมิชนิดดิจิตอลอินฟราเรดสำหรับวัดอุณหภูมิทางหู เปรียบเทียบกับการวัดอุณหภูมิโดยวิธีมาตรฐานคือการใช้ปรอทแก้ววัดอุณหภูมิทางทวารหนัก, 2) ค่าอุณหภูมิที่เหมาะสมในการวินิจฉัยภาวะไข้สำหรับแผ่นวัดอุณหภูมิทางผิวหนังบริเวณหน้าผากและเครื่องวัดอุณหภูมิชนิดดิจิตอลอินฟราเรดสำหรับวัดอุณหภูมิทางหู

วัสดุและวิธีการ: เป็นการศึกษาในเด็กอายุ 0-2 ปี ที่มารับการตรวจรักษาด้วยอาการไข้เป็นอาการสำคัญ ผู้เข้าร่วมการศึกษาทุกรายจะได้รับการวัดอุณหภูมิจากผู้วัดจำนวน 3 รายๆ ละ 1 อุปกรณ์ โดยที่ผู้วัดจะไม่ทราบผลการวัดของผู้วัดรายอื่นๆ ดังนี้ ใช้แผ่นวัดอุณหภูมิทางผิวหนังบริเวณหน้าผากวัด 5 ครั้ง ตามด้วยใช้เครื่องวัดอุณหภูมิชนิดดิจิตอลอินฟราเรดสำหรับวัดอุณหภูมิทางหูวัด 3 ครั้งพร้อมๆ กับการวัดอุณหภูมิโดยวิธีมาตรฐาน คือการใช้ปรอทแก้ววัดอุณหภูมิทางทวารหนัก ข้อมูลค่าเฉลี่ยของวิธีการวัดแต่ละวิธีที่ได้ นำมาเปรียบเทียบค่าเฉลี่ยความแตกต่าง ความสอดคล้องของข้อมูล โดยแบ่งตามระดับความสูงของไข้ด้วยวิธี Bland-Altman statistical methods และศึกษาคุณสมบัติของเครื่องมือชนิดต่างๆ ด้วยวิธี Diagnostic test

ผลการศึกษา: จำนวนประชากรศึกษาทั้งหมด 312 ราย ผลการศึกษาพบว่า อุณหภูมิที่ได้จากการวัดโดยใช้อุปกรณ์ทั้งสองชนิด ต่ำกว่าค่าที่ได้จากการวัดโดยวิธีมาตรฐานคือการใช้ปรอทแก้ววัดอุณหภูมิทางทวารหนัก ค่าเฉลี่ยความแตกต่างของอุณหภูมิเปรียบเทียบระหว่างอุปกรณ์ทั้งสองชนิดกับปรอทแก้ววัดอุณหภูมิทางทวารหนัก พบว่าแผ่นวัดอุณหภูมิทางผิวหนังบริเวณหน้าผากวัดอุณหภูมิได้ค่าต่ำกว่าการวัดจากปรอทแก้ววัดอุณหภูมิทางทวารหนักอย่างมีนัยสำคัญทางสถิติ โดยมีค่าเฉลี่ยความแตกต่างของอุณหภูมิ 1.04 องศาเซลเซียส ($p<0.001$) ส่วนเครื่องวัดอุณหภูมิชนิดดิจิตอลอินฟราเรดสำหรับวัดอุณหภูมิทางหูจะวัดอุณหภูมิได้ต่ำกว่าการวัดจากปรอทแก้ววัดอุณหภูมิทางทวารหนักอย่างมีนัยสำคัญทางสถิติ โดยมีค่าเฉลี่ยความแตกต่างของอุณหภูมิ 1.03 องศาเซลเซียส ($p<0.001$) และเมื่อพิจารณาแยกกลุ่มย่อยตามระดับไข้พบว่า อุปกรณ์ทั้งสองชนิดมีค่าเฉลี่ยความแตกต่างของอุณหภูมิอย่างมีนัยสำคัญทางสถิติในทั้งกลุ่มที่มีไข้สูง กลุ่มที่มีไข้ต่ำรวมทั้งกลุ่มที่ไม่มีไข้ จากการศึกษาคุณสมบัติของเครื่องมือด้วย Diagnostic test เพื่อหาค่าอุณหภูมิที่เหมาะสมในการวินิจฉัยภาวะไข้สำหรับอุปกรณ์แต่ละชนิดให้มีความถูกต้อง (accuracy) สูงที่สุด พบว่าอุณหภูมิ 37.0 องศาเซลเซียสจะมีความถูกต้องแม่นยำสูงที่สุด ในการวินิจฉัยภาวะไข้เมื่อเปรียบเทียบกับการวัดจากปรอทแก้ววัดอุณหภูมิ ทางทวารหนัก

สรุป: แผ่นวัดอุณหภูมิทางผิวหนังบริเวณหน้าผากและเครื่องวัดอุณหภูมิชนิดดิจิตอลอินฟราเรดสำหรับวัดอุณหภูมิทางหู สามารถแนะนำให้ผู้ปกครองใช้ในการตรวจคัดกรองภาวะไข้แก่บุตรหลานในเบื้องต้น แต่ควรปรับลดค่าอุณหภูมิที่ใช้ในการวินิจฉัยภาวะไข้ลงมาเป็น 37.0 องศาเซลเซียส