A Comparative Study on Accuracy of Liquid Crystal Forehead, Digital Electronic Axillary, Infrared Tympanic with Glass-Mercury Rectal Thermometer in Infants and Young Children†

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Abstract

This study was carried out to assess the accuracy of three devices namely, liquid crystal forehead, digital electronic axillary and infrared tympanic thermometer, using a glass-mercury rectal thermometer as the control. The subjects were two hundred children aged 0-48 months. The mean rectal temperature was 38.0 ± 0.91°C; forehead, 37.83 ± 0.94°C; tympanic, 37.77 ± 0.95°C, and axillary, 37.71 ± 0.86°C. Compared to the rectal temperature, all values were significantly lower ($p < 0.05$). Forehead, tympanic and axillary temperature differed from rectal temperature by at least 0.5°C in 33.33 per cent, 23.5 per cent and 31.5 per cent of subjects, and at least 1°C in 22 per cent, 1 per cent and 6 per cent of subjects respectively. Accuracy in detection of fever was 79 per cent for forehead, 85.5 per cent for tympanic and 84 per cent for axillary thermometry. Sensitivity of the three devices was 67-83 per cent in detection of fever and 64-77 per cent in detection of high fever. Tympanic thermometry had the best performance while forehead thermometry had the poorest. After using revised diagnostic threshold temperature by ROC curves, sensitivity of each device improved but accuracy was nearly the same. It is concluded that the three devices are not suitable as a substitute for a glass-mercury rectal thermometer in assessment of fever in infants and young children.

Key word : Thermometers, Comparative Study, Children

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Fever is a common problem in pediatric practice. Assessment for body temperature is mandatory in the management of pediatric patients for the reason that well appearing febrile children may have occult bacteremia in 3 to 11 per cent[1] and the incidence of bacteremia increases as the degree

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of fever increases[2]; therapeutic decisions are also specified in the presence and height of fever. Thus, accurate detection of fever is essential in the management of children[1,3].

Most management guidelines are based on the traditional use of rectal temperature measurement[4-7]. A glass-mercury rectal temperature was previously assumed to reflect core body temperature. This type of thermometer is inexpensive but uncomfortable, time consuming, exposes personnel to contagious disease, has a slow temperature change[8,9] and is easily broken which may cause mercury intoxication, embolism and even death[10-13]. Because of the many limitations of rectal thermometry, new types of thermometers (for example; digital electronic, liquid crystal and infrared thermometer) have been introduced for measuring core temperature from several sites of the body including tympanic membrane, forehead, axilla and mouth. Body temperature measured from different sites usually differs[14]. These new thermometers also correct the measured value equivalent to rectal or core site. The ideal technique is a rapid, painless, easily performed, low cost, without complication and reproducible method.

A liquid crystal forehead thermometer consists of a plastic strip which contains a liquid crystal that changes color in response to heat. It is rapid, easy to use, of low cost, safe and without complication, but, there is uncertainty about its accuracy [15-17] and is more subject to influence by ambient temperature[17]. An infrared tympanic thermometer measures the amount of infrared radiation emitted by the tympanic membrane and nearby soft tissue. The instrument converts the amount of emitted energy into a temperature reading that is digitally displayed. It reflects the core body temperature because the tympanic membrane shares the same vasculature as the hypothalamus[18,19]. It provides a rapid, painless, non invasive measurement and decreases the risk of exposure to infectious diseases for health personnel due to the disposible ear probe cover used in each subject. Because of the relatively small external auditory canal compared to the probe of the instrument, the accuracy of this device in small children has yet to be determined[20-23]. A digital electronic axillary thermometer is a battery operated instrument that detects heat by sensor and is calculated by a microcomputer which gives a digital read out. It is convenient, safe, unbreakable, not too expensive and has no risk of mercury contamination but is time consuming and there are also concerns about the ambient temperature variation that influences the temperature reading[24] and there are some conflicting reports about it's accuracy[22,25,26].

Most thermometers used in previous studies are not commercially available in Thailand. Numerous results and methodologic problems occurred in these studies[20,22,23]. The purpose of this study was to determine the accuracy of thermometers available in Thailand; the liquid crystal forehead, digital electronic axillary, infrared tympanic, compared to the glass-mercury rectal thermometer in infants and young children.

MATERIAL AND METHOD

Two hundred patients, aged 0 day - 48 months with a birth weight of at least 3 kgs, attending the Pediatric Department of the Nakhon Pathom Hospital during the period August to October, 1998 were enrolled. Demographic data including age, gender and diagnosis were recorded. After obtaining parental permission, subjects underwent rectal, forehead, tympanic membrane and axillary temperature measurements simultaneously with a calibrated glass-mercury, liquid crystal forehead (no manufacturer's name), tympanic infrared (model 9000, Welch Allyn, Inc, San Diego, California) and digital electronic thermometer (model C 202, Terumo Corporation, Tokyo) by two investigators. Infants and children having abnormal otic, rectal structure, diarrhea and contagious skin disease were excluded. Glass-mercury thermometers were used by placing the thermometers into the rectums at a depth of 2 cm in neonates and 3 cm in older infants and children for one minute. Forehead temperatures were determined by holding the thermometer strip at both ends and placing the back site of the strip for 20 seconds against the patients' foreheads with firm pressure then the temperature readings appeared in green color. Measuring tympanic membrane temperatures were performed by placing the ear probe of the thermometer (rectal equivalence setting) in the right external auditory canal with a tight seal, retracting the ear posterosuperiorly (posteriorly for children younger than 1 year) and activating the instrument by depressing the scan button, then the temperature was displayed in a digital reading usually within 3 seconds. The axillary thermometer was used by placing the probe next to the skin under the axilla, holding it firmly and waiting for the

instrument to give an audible sound ("beep") when a stable reading was obtained (approximately 1 minute). Measurements by each device in each subject were obtained three times and the means of these values were analyzed. There were four examiners. Two examiners performed four measurements for each child. Before the study, all were instructed to use the four types of devices accurately.

The data were analyzed to test the reliability of the studied devices compared to the rectal thermometry in detection of fever. Temperature difference was calculated as the value with the rectal temperature minus the temperature measured by the studied thermometer. Statistical analysis included Pearson product moment correlation analysis and student t test with significance set at $p < 0.05$. Receiver operating characteristic (ROC) curves were constructed from the data using various temperature thresholds measured by each device for the diagnosis of rectal fever and high fever to evaluate the optimum diagnostic performance of each device.

RESULTS

Of the subjects enrolled in this study, 59 were newborn infants; the others were between 1-12 months (51 subjects), 13-24 months (41 subjects) and 25-48 months of age (49 subjects). Of these, 53 per cent were boys, 60.5 per cent had diseases of the respiratory or cardiovascular system, 16.5 per cent of the gastrointestinal tract, 10 per cent of the central nervous system, 8.5 per cent were normal neonates, 3.0 per cent had systemic infections, and 1.5 per cent had urinary tract diseases. Subjects were categorized by degree of fever using rectal temperatures: afebrile, less than 38°C; low fever, 38.0-38.9°C and high fever, more or equal to 39°C (27). Forehead, tympanic and axillary temperatures showed good correlation with rectal temperatures ($r = 0.7$, 0.93 and 0.90 respectively; $p < 0.01$). The mean temperatures (±SD) were glass-mercury rectal, 38.0 ± 0.91°C; liquid crystal forehead, 37.83 ± 0.94°C; infrared tympanic, 37.77 ± 0.95°C and digital electronic axillary, 37.71 ± 0.86°C. Each value was significantly lower than the mean glass-mercury rectal temperature ($p < 0.05$).

The difference between rectal and the other three temperature methods in individual patients is presented in a histogram (Fig. 1). Most of temperature differences occurred between -0.4°C to 0.5°C. By comparison with rectal temperature; forehead, tympanic and axillary temperature differed by at least 0.5°C in 33.33 per cent, 23.5 per cent and 31.5 per cent of subjects and at least 1°C in 22 per cent, 1 per cent and 6 per cent of subjects respectively.

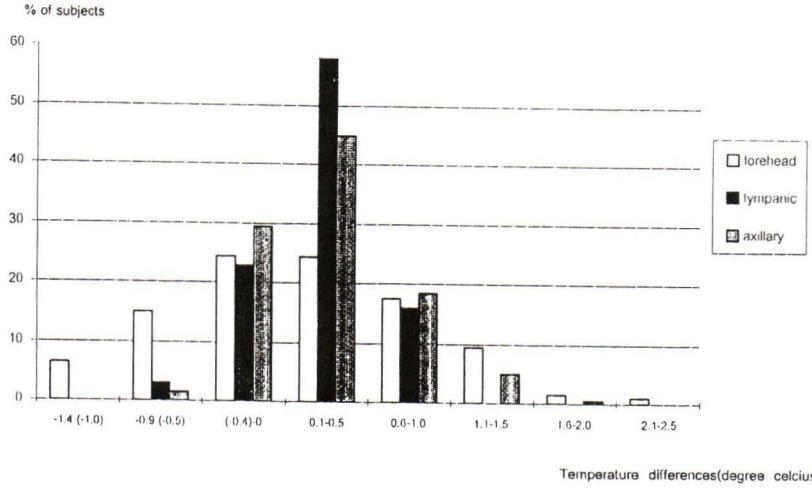

Fig. 1. Frequency histogram of differences between rectal temperatures and temperatures measured with the three alternate methods.

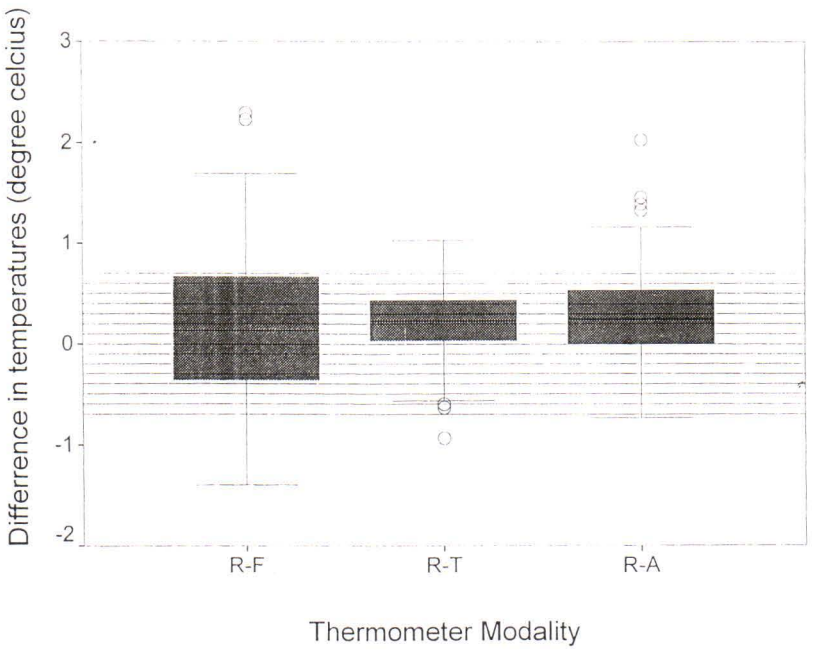

Fig. 2. Box plot representation of differences in temperature measurements between studied thermometers. The solid line in the middle of each box represents the median difference; the area between the top and buttom lines of each box include 75 per cent of the distribution. Any values in the set of data greater than the upper whisker or less than the lower one are considered extreme values and are indicated by a circle. R-F: rectal temperatures minus forehead temperatures; R-T: rectal temperatures minus tympanic temperatures; R-A: rectal temperatures minus axillary temperatures.

Distribution of temperature differences is shown in Fig. 2. Although forehead thermometry had the least value of mean temperature differences than all the other methods, it had the most variability of temperature differences while tympanic thermometry had the least. The performance of studied thermometers in detection of rectal fever and high fever is shown (Table 1). In fever assessment, forehead thermometry had the highest sensitivity and negative predictive value but lowest specificity and positive predictive value. The overall accuracy of forehead thermometry was 79 per cent which was lower than the other devices. Tympanic and axillary thermometry showed a similar performance with a sensitivity of approximately 70 per cent and accuracy of approximately 85 per cent. In high fever, every device had a rather low sensitivity in detection of high fever and poorest performance occurred in forehead thermometry.

ROC curves were constructed from the data, and the optimum temperature thresholds for diagnosing rectal fever and high fever by each device were determined (Fig. 3 and 4). Each point represents the diagnostic utility of each device at a given threshold (in 0.1°C increments). The points which lie the highest vertically from the line of equivalence represent the temperatures yielding the most diagnostic information for detection of rectal fever and high fever. Thus, a threshold of ≥ 37.6°C by every device was the most diagnostic for rectal fever (≥ 38°C); while for high fever (≥ 39°C), the diagnostic utility of both forehead and tympanic thermometry were 38.5°C and of axillary thermometry 38.3°C. The area under the ROC curves for both diagnosis of rectal fever and high fever was lowest by forehead thermometry which reflected the poorest performance by this device. Using revised threshold temperatures, sensitivity of every device

Table 1. Performance of studied thermometer in detection of rectal fever (≥ 38°C) and high fever (≥ 39°C)

	Sensitivity, %		Specificity, %		Positive predictive value, %		Negative predictive value, %		Accuracy, %	
Fever										
Forehead	83.3	87.5	75.0	73.1	75.5	75.0	83.0	86.4	79.0	80.0
Tympanic	71.9	88.5	98.1	86.5	97.2	85.9	79.1	89.1	85.5	87.5
Axillary	67.7	88.5	99.0	92.3	98.5	91.4	76.9	89.7	84.0	90.5
High fever										
Forehead	64.5	87.1	92.3	74.6	60.6	38.6	93.4	96.9	88.0	76.5
Tympanic	77.4	87.1	99.4	92.9	96.0	69.2	96.0	97.5	96.0	92.0
Axillary	67.7	96.8	98.8	87.6	91.3	58.8	94.4	99.3	94.0	89.0

Value in parenthesis were determined by using revised threshold temperatures as determined by ROC analysis. (forehead thermometry, fever ≥ 37.6°C, high fever ≥ 38.5°C; tympanic thermometry, fever ≥ 37.6°C, high fever ≥ 38.5°C; axillary thermometry, fever ≥ 37.6°C, high fever ≥ 38.3°C)

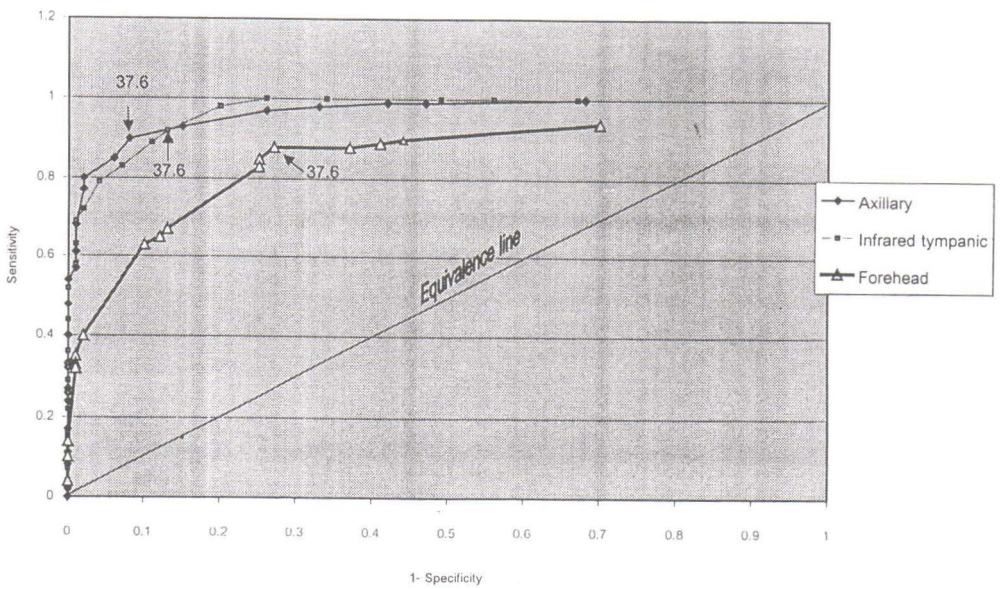

Fig. 3. ROC curves for the diagnosis of rectal fever by studied thermometers (arrows show points that lie the highest vertically from the line of equivalence which represent the temperatures yielding the most diagnostic information).

was better especially in detection of high fever. Negative predictive value was also higher, whereas, specificity and positive predictive value were lower when compared with the previous temperature threshold. The accuracy of the three devices was slightly improved in detection of fever but slightly worse in high fever.

DISCUSSION

The accuracy of thermometers is important in the evaluation of fever. Inaccurate detection of body temperature might lead to mismanagement of sick children including the possibility of omitting an indicated evaluation when fever is underdiagnosed, as well as the potential for performing unnecessary

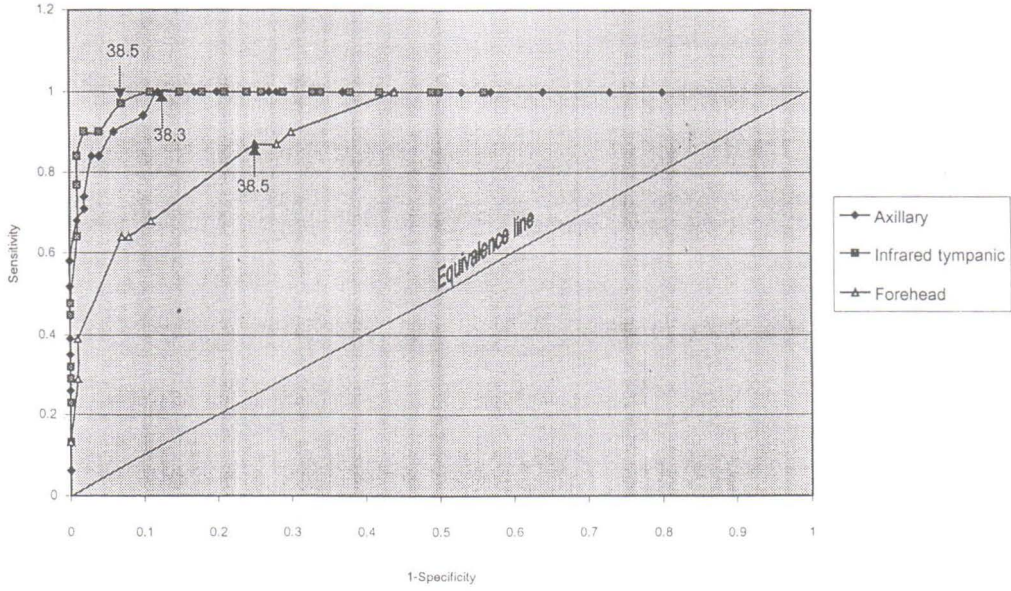

Fig. 4. ROC curves for the diagnosis of rectal high fever by studied thermometers (arrows show points that lie the highest vertically from the line of equivalence which represent the temperatures yielding the most diagnostic information).

and invasive workups when fever has been overdiagnosed. Besides good quality of the thermometer, cooperation of the patient is required. The uncooperative behavior of young children is the main problem in measuring technique. Thus, the ideal thermometer for children should be rapid, safe, easily performed and requires little cooperation. The three studied thermometers used in this report qualify except for the axillary one that consumes more time and requires more cooperation. We used a glass-mercury rectal thermometer as a reference because most management guidelines[4-7] are based on this and it is traditionally used in infants and young children in our hospital.

In our study, results were consistent with others in that there was good correlation between the three studied temperatures and rectal temperatures[17,21,22,26,28-29]. Although there was good correlation between these measurements, approximately one third of subjects measured by both forehead and axillary thermometers and one fourth of the subjects with tympanic measurement had at least 0.5°C difference from the rectal temperature. Twenty two per cent of forehead and 11 per cent of axillary but only 1 per cent of tympanic thermometry subjects had at least 1°C difference from the rectal temperature. This reflected that all of these measurements do not agree well with rectal temperatures as suggested by Bland[29] that the correlation statistic was misleading and might not be used to compare two measurement methods as an indicator of agreement. The lowest agreement with rectal reference and the least area under ROC curves showed that the liquid crystal forehead thermometer had the poorest performance while the infrared tympanic thermometer had the best and was slightly better than the axillary one. The poor performance of the forehead thermometer was possibly due to the least precise scale that had an 0.5°C increment and color that sometimes showed a yellowish or brownish green rather than bright green which made the temperature reading difficult. Bad correlation between rectal and skin temperature especially during fever onset[6,30,31] also influenced the results.

Lewit[17] and Scholefield[15] also found that the forehead did not estimate rectal temperature accurately. Though axillary and tympanic

thermometry had better performance, they can not be substituted for a glass-mercury rectal thermometry because many subjects will be miscategorized regarding level of fever. The bad correlation between skin and rectal temperatures as previously discussed, the improper position of thermometers due to the uncooperative behavior of the toddlers, the relatively large size of the ear probe compared to the children's external auditory canal and the quality of the devices might all affect the readings. Many studies agreed with our findings that axillary [25,30] and tympanic thermometer[22,23,32-34] were inaccurate devices in children. By using the optimum diagnostic thresholds from ROC curves for more accuracy of the devices, their performance was slightly better but many subjects could still be miscategorized regarding level of fever which could have potentially significant diagnostic and therapeutic implications.

A recent study found that tympanic membrane temperature was closer to the core temperature than rectal temperature[14], so it could be a good index of body temperature. Because of the easily used, quickly performed and accurately reflect core temperature, further study on aural tympanic thermometer should be performed. A smaller probe should be made for infants and young children.

Our study had some pitfalls. It was unblinded thus there was potential bias when the same examiner read the values of temperatures from all types of thermometers. Variation in the measuring technique between examiners although giving in-service instruction prior to use may gave a significant influence as observed by other studies[35-37].

We conclude that despite using optimum diagnostic thresholds, some patients will be miscategorized regarding level of fever which causes potentially significant diagnostic and therapeutic implications. We agree with others[15,32,38] that these three devices should not be substituted for a glass-mercury rectal thermometer in fever assessment in infants and young children.

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การศึกษาเปรียบเทียบความแม่นยำของมาตรอุณหภูมิชนิดแถบติดหน้าผาก, ชนิดอิเล็กทรอนิกส์หนีบรักแร้, ชนิดอินฟราเรดวัดทางหู เปรียบเทียบกับชนิดปรอทวัดใช้เหน็บทวารหนักในเด็ก†

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คณะผู้วิจัยได้ศึกษาความแม่นยำของมาตรอุณหภูมิชนิดแถบติดหน้าผาก, ชนิดอิเล็กทรอนิกส์หนีบรักแร้, ชนิดอินฟราเรดวัดทางหู เปรียบเทียบกับปรอทวัดใช้เหน็บทวารหนักในเด็กแรกเกิดถึงอายุ 4 ปี จำนวน 200 ราย พบว่าอุณหภูมิกายเฉลี่ยที่วัดทางทวารหนักเท่ากับ 38.0 ± 0.91°ซ, ทางหน้าผากเท่ากับ 37.83 ± 0.94°ซ, ทางช่องหูเท่ากับ 37.77 ± 0.95°ซ และทางรักแร้เท่ากับ 37.71 ± 0.86°ซ. อุณหภูมิเฉลี่ยที่วัดจากส่วนต่าง ๆ ของร่างกายต่ำกว่าอุณหภูมิเฉลี่ยที่วัดทางทวารหนักอย่างมีนัยสำคัญทางสถิติ ($p < 0.05$). เมื่อเปรียบเทียบค่าความแตกต่างระหว่างอุณหภูมิที่วัดทางทวารหนักกับอุณหภูมิที่วัดจากส่วนอื่น ๆ ของร่างกายในผู้เข้ารับการศึกษาแต่ละรายพบว่าร้อยละ 33.33, ร้อยละ 23.5 และร้อยละ 31.5 ของผู้เข้ารับการศึกษาที่วัดอุณหภูมิโดยใช้มาตรอุณหภูมิชนิดแถบติดหน้าผาก, ชนิดอินฟราเรดวัดทางหูและชนิดอิเล็กทรอนิกส์หนีบรักแร้ มีค่าอุณหภูมิที่วัดได้แตกต่างจากอุณหภูมิที่วัดทางทวารหนักอย่างน้อย 0.5°ซ และร้อยละ 22, ร้อยละ 1 และร้อยละ 6 แตกต่างอย่างน้อย 1°ซ. ค่าความถูกต้องของมาตรอุณหภูมิชนิดแถบติดหน้าผากคิดเป็นร้อยละ 79, ชนิดอินฟราเรดวัดทางหู ร้อยละ 85.5 และชนิดอิเล็กทรอนิกส์หนีบรักแร้ร้อยละ 84 ความไวของมาตรอุณหภูมิทั้งสามชนิดในการวัดไข้คิดเป็นร้อยละ 67–83, และในการวัดไข้สูง คิดเป็นร้อยละ 64–77. เมื่อนำอุณหภูมิใหม่ที่ได้จากกราฟ ROC มาใช้ในการทำนายไข้ พบว่า ค่าความไวของมาตรอุณหภูมิแต่ละชนิดมีค่าสูงขึ้น, ส่วนค่าความถูกต้องมีค่าใกล้เคียงกับค่าเดิม. คณะผู้ทำการวิจัยสรุปว่า มาตรอุณหภูมิทั้งสามชนิดไม่สามารถใช้แทนมาตรอุณหภูมิชนิดปรอทวัดใช้เหน็บทวารหนักในการวัดไข้ในเด็กได้.

คำสำคัญ : มาตรอุณหภูมิ, เด็ก

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