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Original Research Article

Agreement among glass mercury thermometers, infrared thermometers and digital thermometer temperature recordings in febrile under-five children

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ABSTRACT

Background: This study aimed to assess the degree of agreement between the temperature readings of a glass mercury thermometer (GMT), a digital thermometer (DT) and an infrared thermometer (IR) in paediatric patients. This was a comparative study conducted at a tertiary institution in Nnewi, Anambra State, Southeast Nigeria. One hundred febrile children <5 years of age were recruited via convenience sampling.

Methods: Temperatures were measured via an axillary GMT, an axillary DT and a noncontact forehead IR thermometer. Data were compared among the three methods via a 2×2 contingency table, receiver operating curve (ROC) and Bland Altman plot with GMT as the standard.

Results: There was a greater significant correlation between GMT and DT ($r=0.901$, $p=0.001$) than between GMT and IR ($r=0.695$, $p=0.001$). Bland Altman plots revealed that IR and DT could be used interchangeably with GMT with an arithmetic mean of 1.1°C, confidence interval of 0.9359 to 1.1581, limits of agreement of -0.1–2.1 (37.4°C–39.6°C), $p<0.001$, outliers 3% at 1.96 SD and arithmetic mean of -0.1°C, confidence interval of -0.1337-0.00427, limits of agreement of -0.7–0.5 (36.8°C–38.0°C), $p=0.037$ and outliers 4% at 1.96 SD with GMT as the standard against IR and DT, respectively.

The area under the receiver operator curve values were 0.811 and 0.923 for GMT versus IR and GMT versus DT, respectively.

Conclusions: Digital and infrared temperature readings are in reasonable agreement with a glass mercury thermometer and both can be used interchangeably with a glass mercury thermometer. Compared with infrared thermometers, digital thermometers are more closely related to glass mercury thermometers.

Keywords: Agreement, Digital thermometer, Glass mercury thermometer, Infrared thermometer, Temperature

INTRODUCTION

Fever is one of the most common symptoms and signs of paediatric illnesses, especially in children under five years of age.[1] This condition is usually characterized by an increase in body temperature. Therefore, body temperature is a measure of the body's ability to generate and dissipate heat. Physiologically, the body temperature of a normal patient is within a normal safe range despite temperature variations around our environment.[2] The hypothalamus regulates body temperature by comparing current temperature with normal body temperature and either stimulates increases in heat generation and maintenance when the temperature of the body is low or stimulates heat dissipation through sweating when the body temperature is high. This hypothalamic regulation of body temperature is less efficient in younger children than in older children and adults. Sweating is also less common in these younger children and hence, their reaction to fever is greater.[3]

Temperature variations occur during the day, with the highest occurring in the early hours of the morning (between 2 am and 4 am) and then peaking in the afternoon. Other factors that may increase heat generation with a consequent increase in body temperature are overdressing and strenuous exercise, especially during hot weather.[2] The normal temperature ranges from 36.5°C–37.4 °C.[4] Fever is a temperature≥37.5°C.[4-6] The causes of fever vary in etiology and are often a manifestation of minor or severe ailments. They can be of infective origin, such as bacteria, viruses, parasites, etc.; inflammatory conditions; and immunizations, such as pentavalent, pneumococcal or COVID-19 vaccines; cancers; and medications.[7] Fever caused by different etiologic agents is the most common cause of hospital admissions and deaths in children aged less than 5 years in developing countries.[7]

A thermometer is a clinical device used for measuring body temperature. Temperature measurements must be accurate, valid and reliable, as clinical decisions, therapeutic interventions and referrals are based on the temperature level of a patient. False readings may lead to omission, misdiagnosis or delays in necessary treatment.[8-10]

Body temperature can be measured via a glass mercury thermometer (GMT), digital thermometer (DT) or noncontact infrared thermometer (IR)2 and the sites for measurements include the axilla, mouth, forehead, rectum, ear, etc.[11] An ideal temperature measurement device should be reliable, nontraumatic, noninvasive, considerably acceptable, friendly and hygienic. Oral and rectal temperatures provide better readings of the body core temperature.

However, oral temperature measurement is unhygienic and difficult in children. The rectal temperature is unhygienic, uncomfortable and unacceptable in many countries, whereas axillary temperature measurement is more acceptable in most countries.[12-14] Measurement of axillary body temperature via the GMT has been the gold standard for over a century.[15-17] Nevertheless, glass mercury thermometers pose the danger of breakage and mercury intoxication. The era of COVID-19 has also highlighted the introduction of noncontact IR thermometers.

As clinical practice is advancing, the world is shifting away from GMT due to the dangers of breakage and mercury intoxication. Developing countries are not left out in this shift. Although several studies are ongoing globally, none have been performed in our setting. Hence, the research question is “Is there any difference in the temperature readings of the GMT, DT and IR. The purpose of this study was to evaluate the agreement between the temperature readings of the axillary temperature of the GMT, which is the gold standard in our setting, the axillary DT and the noncontact IR thermometer measured on the forehead.

METHODS

Study design

This study was a single-center cross-sectional comparative study.

Study place

This study was conducted in the children 2024 emergency room of Nnamdi Azikiwe University Teaching Hospital (NAUTH), which is located in Nnewi, Anambra State.

NAUTH is a tertiary healthcare institution, being one of the two such institutions in the state and the sole federal government-owned facility. It serves as a comprehensive healthcare provider, delivering primary, secondary and tertiary medical services to the population residing in Nnewi and its surrounding areas. Nnewi is a commercial city situated in the Nnewi North Local Government Area of Anambra State, with an estimated population exceeding 900,000 as of 2019.[18] The residents of Nnewi are predominantly Igbos, mainly traders and civil servants.

Study duration

The study spanned a period of 2 months from June–August 2004.

The paediatric healthcare facilities within NAUTH include the Children Emergency Room (CHER), Paediatric Wards and Children Outpatients Clinic (CHOP). The CHER operates around the clock, providing emergency care services seven days a week. The CHER is manned by 2 consultants, 2 registrars and 1 medical officer. On average, approximately 4 patients are admitted daily to CHER.

Study population

The study population included one hundred under five children who presented to CHER with fever.

Inclusion criteria

Children greater than 1 year and less than 5 years of age who presented to the children’s emergency room with fever whose mothers gave consent were included.

Exclusion criteria

Children who are highly irritable or unconscious, children with infections/ulcerations at the axilla, children whose caregivers declined to participate

Sample size calculation

The sample size was calculated via the G-power statistical package 3.0.10.[19] A sample size of 100 had 87% power to detect a moderate change of 0.3 at an alpha level of significance of 0.05.

Sampling technique

Participants were recruited via a convenient sampling technique until the sample size was reached.

Instruments used and data collection procedure

The data were collected via questionnaires, which consisted of two parts: Part I, demographic characteristics and Part II, temperature recording.

The temperature was measured via GMT, DT and IR noncontact thermometers on clean dry skin. The devices and sites that were used in this study are the axillary GMT, axillary DT and noncontact IR forehead thermometer. The GMT, Agary fever (product code 0197 1/100C), easy-to-read DT (mode C-004) and Tecno noncontact IR thermometer (model E-300) were used. A ±0.10C measurement error was reported for GMT and DT by the manufacturer (body temperature range from 35.5 to 42.00C) and a ±0.20C error was reported for the forehead IR thermometer. For each of the devices, two temperature recordings were taken and the average was determined. For the IR thermometer, the forehead was used. The forehead was cleaned with a clean dry towel and stabilized with the left hand. The light of the IR thermometer was focused on the forehead without having contact with the skin using the right hand until a beep sound was heard. This process was performed twice and the average temperature was recorded in degrees Celsius (°C).

Two temperature readings were taken from the axilla (one from each axilla) via the DT. Before the temperature was measured, the armpit was cleaned with a clean dry towel. The DT was switched on and the temperature at zero before inserting the bulb deep into the axilla. The caregiver was asked to support the hand firmly. The thermometer was in the axilla until a beep heard. The average temperature was recorded in degrees Celsius (0C).

Two measurement readings were also taken from both axilla via the GMT. Before the temperature was measured, the armpit was also cleaned with a clean dry towel. The thermometer was held at the top end and shaken so that the mercury dropped below 35°C. The bulb of the thermometer was placed deep into the axilla for 5 minutes, as stipulated by the Integrated Management of Newborn and Childhood Illness (IMNCI) guidelines and timed with a stop watch and temperature recorded at ºC to an accuracy of 0. 10C.[20]

The demographic characteristics and other variables of the participants were collected from the caregivers.

Two qualified nurses were trained on the proper usage of the temperature measuring devices and the completion of questionnaires and they assisted in that capacity.

Data analysis

Data were analysed via SPSS version 21 (IBM Corp., Armonk, New York, USA). Descriptive statistics was used to describe the participants' demographic characteristics and temperature readings. One-way ANOVA was used to compare the mean readings between the DT, GMT and IR thermometers.

The Pearson correlation coefficient was used to determine the linear association between the readings of the three thermometers (to determine the concurrent validities of the DT and IR thermometers) and the extent of agreement (homoscedasticity) of the values measured by the three thermometers was assessed with Bland–Altman plots. The correlation coefficients are interpreted as follows: r<0.3=poor correlation, 0.3–0.5=slight correlation, 0.6–0.8=moderate correlation and >0.80=excellent correlation.[21] The sensitivity, specificity and predictive values are calculated for DTs and IRs using the GMT as the gold standard. The receiver operating curve is plotted to show the diagnostic accuracy of the DT and IR using the GMT. P values<0.05 were considered statistically significant.

RESULTS

One hundred children aged 1 month to < 5 years who presented at the outpatient clinic were studied. Thirty-seven (37%) were females, whereas 63 (63%) were males. The female: male ratio was 1:1.7.

Approximately 38% of the children were under 1 year of age. The mean age of the children was 19.97±14.33 months. The majority of the caregivers (81%) were females (Table 1). The majority (72%) of the children presented to the clinic during the morning hours, whereas the rest presented during the afternoon and evening hours. Only 34% and 16% of the patients had paracetamol and tepid sponged, respectively, for ≤30 min prior to the temperature measurements. The majority of the children (62.83%) were diagnosed with and treated for malaria (Table 2).

The mean temperatures recorded among the children were 38.60±0.74ºC, 38.53±0.670C and 37.47±0.740C for the DT, GMT and IR thermometers, respectively. The glass mercury and digital thermometers had closer mean temperatures than the infrared thermometers did, as shown in Table 3.

One-way ANOVA revealed a significant difference between the mean temperatures measured with the DT, GMT and IR thermometers (F=-4.378; p=0.023), as shown in Table 4. The GMT and DT were able to detect fever in 98% of the subjects each, whereas the IR thermometer detected fever in only 55% of the subjects, as shown in Table 5.

However, the Pearson coefficient correlation analysis between the digital and glass mercury thermometers revealed a very strong correlation. (r= 0.901, p=<0.01)), indicating the excellent concurrent validity of the digital thermometer. The correlations between the DT and IR thermometers and between the GMT and IR thermometers were only moderate. (r=0.645, p=0.01) and (r=0.695, p=0.01), respectively.

Compared with the GMT, the DT was highly sensitive (97.6%), with a positive predictive value of 100% and an accuracy of 100%, as shown in table 6. In contrast, the comparison of the infrared thermometer with the glass mercury thermometer revealed a lower sensitivity of 56.7%, an accuracy of 57% and a specificity of 100%, as shown in Table 6.

The sensitivity, specificity, positive predictive value and negative predictive value of a digital thermometer for detecting fever when mercury in a glass thermometer is the gold standard

Sensitivity=TP/TP+FN=96/98×100=97.96%

Specificity=TN/TN+FP=0/0+2×100=0%

Positive predictive value=TP/TP+FP=96/96×100=100%

Negative predictive value=TN/TN+FN=0/0+2×100=0%

Accuracy=TP+TN/Total=96+0/100=0.96=96%

The sensitivity, specificity, positive predictive value and negative predictive value of infrared thermometer for detecting fever when mercury in a glass thermometer is used as the gold standard

Sensitivity=TP/TP+FN=55/97×100=56.70%

Specificity= TN/TN+FP=2/2×100=100%

Positive predictive value=TP/TP+FP=55/55×100=100%

Negative predictive value=TN/TN+FN=2/44×100=4.5%

Accuracy=TP+TN/Total=55+2/100=0.57=57%.

Figure 1(a) is a scatter diagram showing the level of linear association between the readings of the digital and glass mercury thermometers with the temperature values clustering together towards the center, showing a strong association between them, whereas Figure 1(b) shows less clustering of values between the GMT and IR thermometers. There were no significant outliers.

A Bland–Altman plot was generated to determine the extent of agreement between the GMT, DT and IR thermometers. The plot between GMT and IR presented a wider 95% confidence interval (0.030063-- (-2.14326) 0C), as shown in Figure 1a, than did the plot between GMT and DT (0.704915--0.57351) ºC), as shown in Figure 1(b).

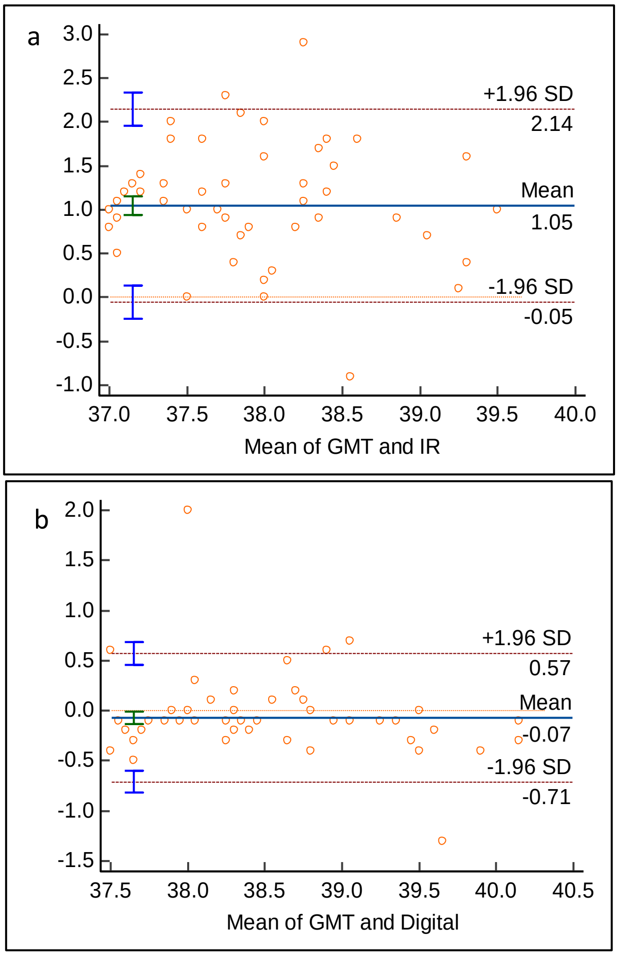

Figure 1: (a) Bland–Altman plots between GMT and IR plus the observed mean difference and 95% limits of agreement. (b) Bland–Altman plots between GMT and Digital plus the observed mean difference and 95% limits of agreement.

(a) Outliers=3 (0.03%), GMT=glass mercury thermometer. IR=infrared thermometer. SD=standard deviation. N=number of study subjects. (b) Outliers=4 (0.04%), GMT=glass mercury thermometer. Digital=digital thermometer. SD=standard deviation. N=number of study subjects.

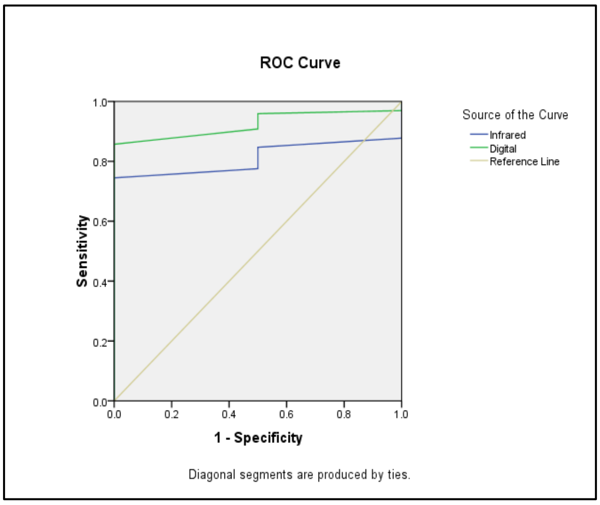

Figure 2: ROC curve.

This implies that at every instance, owing to systematic error, the concurrent values recorded by the GMT and IR on the same patient could differ from 2.14ºC (which is clinically significant), with the IR being more likely to give a lower score.

On the other hand, the concurrent values recorded by the GMT and DT could differ from 1.28ºC (which may be considered less clinically significant).

This shows that the values measured with the GMT are better approximated by the values measured with the GMT, which are approximated by the values measured with the DT and those measured with the IR.

Bland–Altman plots with GMT as the standard against IR also revealed that the bias (arithmetic mean) was (1.1°C), the confidence interval ranged from 0.9359--1.1581, the limits of agreement were (-0.1–2.1 (37.4°C–39.6°C)), p<0.001 and 3% of the outliers were 1.96 SD (Table 7, Figure 1(a)).

Similarly, GMT versus Digital temperature showed a bias (arithmetic mean) of -0.1°C, confidence interval of -0.1337 to 0.00427, limits of agreement of -0.7–0.5 (36.8°C–38.0°C), p=0.037 and outliers of 4% at 1.96 SD (Table 7, Figure 1(b)). This finding showed that both IR and Digital could be used interchangeably with GMT.

Compared with those of the glass mercury thermometer, the ROC curves of both tools were above the reference line, indicating that both tools are good tools for temperature measurement.

However, the digital thermometer covered a wider area than the infrared thermometer, with areas of 0.923 and 0.809, respectively, making the accuracy of the digital thermometer closer to that of the glass mercury thermometer than that of the infrared thermometer, as shown in Figure 2.

For GMT versus IR, the area under the receiver operator curve (AUROC) was 0.811 and for GMT versus DT, the AUROC was 0.923. The IR at the best cut-off of 37.4°C was 37.5°C (sensitivity 57.1%), whereas the DT at the best cut-off of 37.4°C was 37.5°C. (sensitivity -98.0%) (Figure 2).

Table 1: Sociodemographic variables of the subjects.

Variable	Frequency	(%)
Gender		
Female	37	37.0
Male	63	63.0
Age (months)		
Less than 12 months	38	38.00
12-24 months	33	33.00
Above 24 months	29	29.00
Mean (±SD)	19.97±14.33	
Median (Interquartile range)	15 (10-28)	
Minimum age	4 months	
Maximum age	59 months	
Gender of Caregiver		
Female	81	81.0
Male	19	19.0
Total	100	100.0

Table 2: Other variables of the subjects.

Variable	Frequency	(%)
Time of presentation		
Morning	72	72

Continued.

Variable	Frequency	(%)
Night	28	28
PCM intake within 30 minutes of presentation		
No	66	66
Yes	34	34
Bath within 30 minutes		
No	84	84
Yes	16	16
Diagnosis *(n=113)* *		
Bronchopneumonia	17	15.05
Malaria	71	62.83
Otitis media	12	10.62
Sepsis	6	5.31
Upper respiratory tract infection	7	6.19

*=multiple response variable.

Table 3: Summary statistics for the digital, glass mercury and infrared thermometers.

Thermometer	Statistics
Digital thermometer	
Mean (±SD)	38.60±0.74
Median (Interquartile range)	38.4 (38.0-39.0)
Minimum temperature	37.0
Maximum temperature	40.3
Glass mercury thermometer	
Mean (±SD)	38.53±0.67
Median (Interquartile range)	38.4 (38.0- 38.95)
Minimum temperature	37.3
Maximum temperature	40.1
Infrared thermometer	
Mean (±SD)	37.47±0.73
Median (Interquartile range)	37.5 (36.8-37.9)
Minimum temperature	36.4
Maximum temperature	39.1

Table 4: One-way ANOVA comparing the mean readings between the digital thermometer, glass mercury thermometer and infrared thermometer.

	Reading (mean±SD)	f value	P value
Digital thermometer	38.60±0.74	-4.378	0.023*
Glass mercury thermometer	38.53±0.67		
Infrared thermometer	37.47±0.73		

*=significant p value<0.05.

Table 5: The three different methods of temperature measurement and Pearson correlation showing the level of linear association in the readings between the three thermometers used in the study.

Method	Normal (36.6-37.4) (%)	Fever (≥ 37.5) (%)
Mercury-in-glass thermometer	2 (2.0)	98 (98.0)
Digital thermometer	2 (2.0)	98 (98.0)
Infrared thermometer	44 (44.0)	55 (55.0)
Variable	**Pearson correlation coefficient (r)**	**P value**
Digital thermometer vs Glass mercury thermometer	0.901	<0.001*
Digital thermometer vs infrared thermometer	0.645	0.001*
Glass mercury thermometer vs infrared thermometer	0.695	0.001*

*=significant p value<0.05.

Table 6: Sensitivity, specificity, positive predictive value and negative predictive value of digital and infrared thermometers in detecting fever using mercury in glass thermometers as the gold standard.

Variables		Mercury in glass thermometer		
		Normal	**Fever**	**Total**
Digital thermometer	Normal	a (TN)	b (FN)	(a+b)
		0	2	2
	Fever	c (FP)	d (TP)	(c+d)
		2	96	98
	Total	(a+c)	(b+d)	100
		2	98	
		Normal	**Fever**	**Total**
Infrared thermometer	Normal	a (TN)	b (FN)	(a+b)
		2	42	44
	Fever	c (FP)	d (TP)	(c+d)
		0	55	55
	Total	(a+c)	(b+d)	
		2	97	99

TP: True positive, FN: False negative, FP: False positive, TN: True negative.

Table 7: Summary of Bland Altman plots of agreement between GMT, IR and Digital.

ºC	GMT vs IR	GMT vs Digital
Bias (Arithmetic mean)	1.0470	-0.004276
95% Confidence interval	0.9359-1.1581	-0.1337 - -0.004276
Limits of agreement (lower)	-0.05025	-0.7083
Confidence interval	-0.2408-0.1402	-0.1337 - -0.004276
Limits of agreement (upper)	2.1443	0.5703
Confidence interval	1.9538-2.3348	0.4594-0.6813
P (Ho: Mean=0)	<0.001	0.037

GMT=glass mercury thermometer. IR=infrared thermometer. Digital=digital thermometer. ºC=degree centigrade. vs=versus

DISCUSSION

There is a trend toward the use of GMT to alternative devices across the globe to protect humans and the environment from mercury intoxication. Numerous user- and environmentally friendly devices have been available for use in clinical practice worldwide over the last 10 years and several studies have been conducted to assess their reliability.[22-24]

The purpose of these assessments is to reduce the risk of misdiagnosis and, consequently, unnecessary treatment. The participants used in this study were under five children with febrile illnesses. A similar age group was used in the study done in Ethiopia, unlike studies done in India, which used healthy neonates, Turkey, which included healthy infants and healthy young children aged 18-24 years and Malaysia, which included all age groups.[25-28]

The mean age of the subjects was 19.97±14.33 months, while their mean temperature readings were 38.60±0.74, 38.53±0.67 and 37.47±0.73 for the DT, GMT and IR thermometers, respectively. Notably, the mean temperatures between the DT and the GMT were closer to each other than the mean temperatures from the IR thermometer and the IR having a lower mean temperature reading.

The mean differences among the GMT, DT and IR groups were statistically significant (p=0.023). However, DT was more strongly correlated with GMT than was IR (r=0.901, p<0.001 and r=0.695, p=0.00, respectively). The mean differences between GMT and 1R and between GMT and DT were -1. 0566) and (0.0657), respectively, with the means of DT and GMT closer to zero and therefore more precise and had better concordance with GMT than the IR.

Similar findings were reported in Ethiopia, Iran and the USA, in which the DT had better agreement with the GMT than the IR did. This finding was further supported by the fact that both the GMT and DT were able to detect fever in 98% of the participants.[24,29-31] Second, the DT, compared with the GMT, was highly sensitive (97.6%), with a positive predictive value of 100% and an accuracy of 100%. In contrast, the comparison of the infrared thermometer with the glass mercury thermometer revealed a lower sensitivity of 56.7%, an accuracy of 57% and a specificity of 100%. Therefore, from this study, the digital thermometer can be said to be a better replacement for GMTs than the IR noncontact thermometer. However, compared with those of the glass mercury thermometer, the curves of the digital and infrared thermometers were above the reference line, with areas of 0.923 and 0.809 for DT and IR, respectively, indicating that both are good tools for temperature measurement. This implies that although digital thermometers are better replacements for traditional GMTs, IR thermometers still find their place in clinical practice because they are user friendly, fast and convenient for screening large populations, especially during pandemics.

The strength of this study lies in the fact that this study was one of the few that compared the temperature readings of GMT, ID and IR in children. This study provides an opportunity to evaluate the interchangeability of the new DT and IR devices with the axillary GMT historically used in clinical practice.

The study was performed in real clinical settings and the results were analysed with appropriate statistical packages.

The study was limited by its small sample size, which may limit its generalizability. The inability to compare the temperature readings in this study with core temperature measurements and the fact that the temperature readings might have also been prone to subjective variations in temperature recordings were also limitations of this study.

CONCLUSION

Digital and infrared methods of assessing temperature have a reasonable level of agreement with glass mercury and both digital and infrared thermometers could be used interchangeably with glass mercury thermometers in children in this study. The digital thermometer was more closely related to the glass mercury thermometer than the infrared thermometer with the glass mercury thermometer.

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Ethical approval: The study was approved by the Institutional Ethics Committee

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