Original Article

Risk Factors Associated with Measurement Error across Different Types of Commonly Used Thermometers: A Cross-Sectional study from Ethiopia

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Abstract

Background: No studies have compared infrared skin and sublingual thermometers to explore which factors may modify temperature measurement error.

Objectives: To identify the measurement error with thermometers used in Ethiopia and the factors that may modify these errors.

Methods: An observational study design was used. The study population comprised individuals attending a teaching hospital in Ethiopia. Data were collected on sublingual and infrared skin temperatures and compared with axillary temperature measurements.

Results: Data were available from 2118 individuals (mean age of 43.2 years; 1310 (62%) were male). Among these individuals, 384 (18%) had temperature reading that differed by 0.5 °C or more from the axillary temperature when measured using the infrared thermometer. The corresponding figure for the sublingual thermometer was 365 (17%) individuals. Both thermometers showed an inverse association between mean temperature relative to the reference axillary temperature and measurement error ($p<0.001$ for both regression models).

For the infrared skin thermometers, post-menopausal women who had a positive measurement error (+0.621; 95% CI: confidence intervals: +0.462 to +0.781), while a negative measurement error was associated with pregnancy, recent consumption of a hot or cold drink, higher body mass index, ambient relative humidity (-0.571°C; 95%CI: -0.624 to -0.518; highest tertile vs. lowest) and taking beta-blockers (-0.351°C; 95% CI: -0.416 to -0.286). Some of these modifying factors were also evident for sublingual thermometers, including beta-blockers use (-0.108°C; 95% CI: -0.163 to -0.052) and ambient humidity.

Discussion: As sepsis accounts for approximately 20% of all global deaths, these observations should inform further studies in this area, with a particular consideration given to factors such as beta-blockers and ambient humidity. These data also raise concerns about the use of infrared skin temperature measurements in post-menopausal women.

Conclusion: The measurement errors of infra-red skin and sublingual thermometers are modified by several risk factors, many of which modify peripheral circulation. [*Ethiop. J. Health Dev.* 2026; 40(2)]

Keywords: Body temperature, Measurement error, thermometers, sepsis, hypotension, shock

Introduction

Body temperature is one of the key clinical vital signs and has been used for centuries by healthcare workers to diagnose disease and guide treatment decisions. In recent decades, the range of thermometers available for measuring temperature has expanded rapidly, with different technologies used to measure temperature at different sites on the body. However, this introduces the possibility that body temperature may vary across different measurement sites, and these potential differences may be compounded by measurement error between the differing methodologies used to measure temperature. A further concern is that body temperature measurement often depends on blood circulation to the peripheral surfaces of the body where the temperature is recorded (1). Hence, factors such as age, sex, use of beta-blockers, tobacco smoking, and pregnancy that may modify blood flow to the skin have the potential to be risk factors for temperature measurement error.

Body temperature can be measured from the mouth, axilla, or rectum in a clinical setting, and representing the traditional approach used for decades. However, sublingual temperature measurements are potentially susceptible to measurement error if hot or cold drinks have been consumed recently, and rectal temperatures are not widely measured. Many institutions have now adopted the use of infra-red thermometers, which are non-invasive, making measurements quicker and reduce the risk of cross-infection. These devices use an infra-red signal reflected off the skin and convert the reflected signal into a temperature reading using an algorithm. The most comprehensive data comparing different methods of measuring temperature comes from emergency department patients from the USA,

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where over 35% of recorded temperatures differed by 0.5 degrees Centigrade or more (2).

This study explores the difference between axillary temperature readings and sublingual and infrared skin temperature measurements in individuals attending a busy teaching hospital in Addis Ababa, Ethiopia. Data were collected on demographic factors and exposures that may modify measurement error across these different methods of measuring temperature.

Methods

Study Population

The study population consisted of individuals who attended Tikur Anbessa Specialized Hospital, Addis Ababa, which is a large teaching hospital serving the general population, from August to December 2025. Some individuals were patients, while others were visitors. Patients were approached in the outpatients section of the hospital, and data were collected if the individual agreed to participate and provided consent. There was no sampling frame, and all eligible individuals were approached.

Data collection

Once informed consent had been provided, data were collected on demographic characteristics and simple exposures including beta-blocker prescription, pregnancy, menopause, smoking and smokeless tobacco use, and recent (< 15 minutes) consumption of hot or cold drinks. Data collection staff were trained before data collection begun to insure a standardised approach. The data collection process was initially piloted, and the data were reviewed after 300 individuals to ensure that data collection was being conducted appropriately. Ambient temperature and relative humidity were measured using a digital wall thermometer (HTC-1 Digital Thermometer/Hygrometer with Clock). The device was mounted on the wall, and measurements were recorded simultaneously with the participants' body temperature measurements. Axillary and oral temperatures were recorded using a Heuer Digital Thermometer (15-581) (3), while infra-red temperature measurements at the forehead was recorded using a STBH-II infra-red skin thermometer manufactured by Guangdong Stable Medical Technology Company (4).

Statistical analysis

The reference method of temperature measurement was axillary temperature. The difference between axillary temperature and both infrared and sublingual temperature measurements was calculated by subtracting the axillary temperature from the paired individual infra-red and sublingual temperature measurements. Initial statistical analysis used paired t-tests to explore these differences. To allow comparison with precision measured in similar studies (2), the number of infra-red and sublingual temperature readings that differed from axillary temperature by 0.5 degrees Centigrade or more were calculated. Linear regression was then used to explore the univariate associations between demographic factors and environmental exposures with the measurement error for the infrared and sublingual temperature measurements. Continuous variables were assessed for linearity by comparing the best fit of a categorical model using tertiles with that of the continuous model and testing for similarity using likelihood ratios. Factors that showed a significant association between exposures and temperature measurement errors, defined as a p-value of 0.05 or less, were then adjusted for age and sex in multivariate regression analysis. As this was a study of clinical risk factors in a medium-sized dataset, these analyses represented the final analyses. With little prior data to inform a power calculation, we initially aimed to collect data from approximately 10 000 individuals. However, due to initial difficulties with equipment failure and logistical constraints, data collection was restricted to just over 2000 individuals.

Ethics committee approvals

The study was approved by Ethics Committees of the College of Health Sciences, Addis Ababa University and the University of Nottingham.

Results

Data were available from 2118 individuals, who had a mean age of 43.2 years, of whom 1310 (62%) were male (Table 1).

Table 1: Study population and exposures

	Number (Total population = 2118)	Percent/Standard deviation
They are a patient, %	1055	50%
Male sex, %	1310	62%
Mean age, years, SD	43.2	13.5
Taking beta-blockers, %	461	22%
Currently pregnant*, %	51	6%
Post menopause*, %	334	41%
Current smokers, %	213	10%
Current users of smokeless tobacco, %	226	11%
Had a hot drink within 15 minutes of temperature measurement, %	38	2%
Had cold drink within 15 minutes of temperature measurement, %	574	27%
Mean body mass index, kg/m^2, SD	23.9	2.9
Mean room temperature at time of temperature measurement °C, SD	20.2	2.0
Mean percent ambient humidity at time of temperature measurement, sd	45.7	4.3
Axillary temperature °C, sd	36.3	0.6
Infra-red skin temperature °C, sd	36.3	0.2
Sublingual temperature °C, sd	36.4	0.5

*Women only

Compared with the temperature measured at the axilla, both infra-red skin thermometer temperature and sublingual thermometer temperature measurements were higher (infra-red +0.09 °C; 95% confidence interval [CI: 0.06 to 0.11; sublingual +0.17 °C; 95% CI: 0.15 to 0.19, paired t-test). A total of 384 (18%) individuals had a temperature reading deferred by 0.5 °C or more from the axillary temperature when measured using the infra-red thermometer. The corresponding figure for the sublingual thermometer was 365 (17%) individuals.

The association between the difference in temperature measured by the infra-red skin thermometer and the reference value of axillary temperature, and the mean of these two values, is presented in Figure 1. There was an inverse association, with a one degree Centigrade increase in the mean temperature being associated with a decrease of 1.35°C (95% CI: 1.30 to 1.40) in the difference. The corresponding association for the sublingual temperature is presented in Figure 2. There was a smaller inverse association, with a one degree Centigrade increase in the mean temperature being associated with a decrease of 0.20°C (95% CI: 0.16 to 0.25) in the difference.

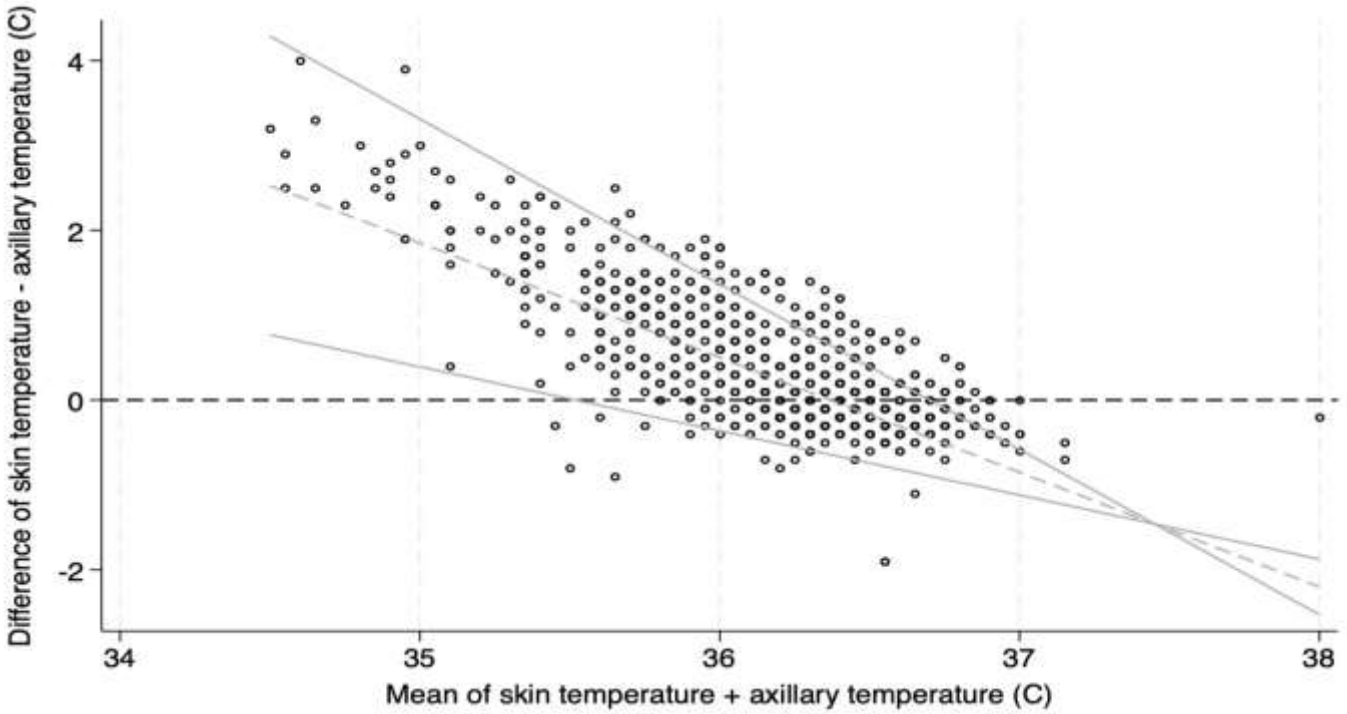

Figure 1: Bland-Altman plots of association between infra-red temperature measurements compared to axillary temperature.

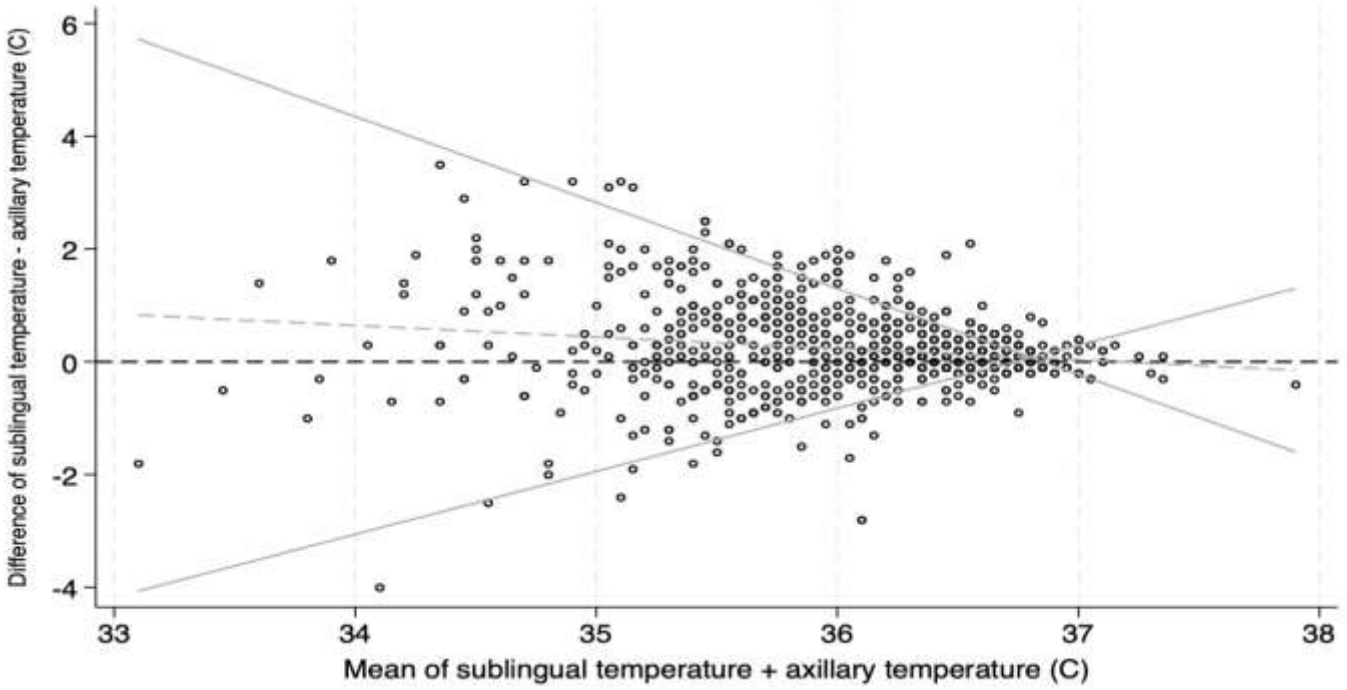

Figure 2: Bland-Altman plots of association between sublingual skin temperature compared to axillary temperature.

In the univariate analyses (Tables 2 and 3), male sex was associated with measurement error for both infrared skin thermometer and sublingual temperature measurements (-0.102 °C; 95% CI; -0.153 to -0.051 and -0.079 °C; 95% CI: -0.121 to -0.036 respectively). Age was positively associated with greater measurement error for infrared skin temperature measurements but not for sublingual temperature measurements.

Infra-red temperature measurement error

In the multivariate analyses (Table 2), age remained positively associated with greater measurement error for infra-red skin temperature measurements.

Table 2: Univariate and multivariate analyses of risk factors for measurement error of infra-red skin temperature measurements compared to core temperature as measured by axillary temperature

	Univariate analysis	Multivariate analysis adjusted for age* and sex
Male sex	**-0.102 (-0.153 to -0.051)**	**-0.104 (-0.155 to -0.053)**
Age, years		
18-35	**ref**	**ref**
36-48	**+0.011 (-0.05 to +0.071)**	**+0.020 (-0.040 to +0.081)**
49-90	**+0.143 (+0.082 to +0.204)**	**+0.148 (+0.087 to +0.208)**
Taking beta-blockers	**-0.214 (-0.273 to -0.154)**	**-0.351 (-0.416 to -0.286)**
Currently pregnant*	**-0.307 (-0.490 to -0.125)**	**-0.265 (-0.454 to -0.076)**
Post menopause*	**+0.277 (+0.188 to +0.366)**	**+0.621 (+0.462 to +0.781)**
Current smokers	**-0.284 (-0.366 to -0.202)**	**-0.230 (-0.315 to -0.144)**
Current user of smokeless tobacco	**-0.262 (-0.342 to -0.182)**	**-0.206 (-0.290 to -0.122)**
Had hot drink within 15 minutes of temperature measurement	**-0.303 (-0.489 to -0.116)**	**-0.291 (-0.477 to -0.106)**
Had cold drink within 15 minutes of temperature measurement	**-0.346 (-0.400 to -0.292)**	**-0.336 (-0.390 to -0.283)**
Body mass index, kg/m^2		
1st tertile (11-23)	**ref**	**ref**
2^{nd} tertile (23-25)	**-0.211 (-0.271 to -0.150)**	**-0.221 (-0.282 to -0.162)**
3^{rd} tertile (25-45)	**-0.120 (-0.179 to -0.060)**	**-0.140 (-0.201 to -0.080)**
Room temperature at time of temperature measurement, °C,	+0.008 (-0.004 to +0.021)	-
Ambient percent humidity at time of temperature measurement, %		
1^{st} tertile (19-44)	**ref**	**ref**
2^{nd} tertile (45-48)	**-0.528 (-0.582 to -0.474)**	**-0.518 (-0.572 to -0.464)**
3^{rd} tertile (49-50)	**-0.582 (-0.635 to -0.530)**	**-0.571 (-0.624 to -0.518)**

Difference defined as infra-red skin temperature – axillary temperature
*Age in tertiles
Bold text = $p<0.05$

Women who were post-menopause were observed to have a positive measurement error using the infrared thermometer, with temperature measurements higher than the axillary temperature measurements. A negative measurement error, i.e. an infrared skin temperature measurement that was lower than the axillary temperature measurement, was associated with beta-blocker use, current smoking, current smokeless tobacco use, consumption of hot or cold drink within 15 minutes of temperature measurement, body mass index and ambient relative humidity at time of temperature measurement.

Sublingual measurement error

In the multivariate analyses, after adjusting for sex, sex remained positively associated with higher measurement error for sublingual temperature measurements (Table 3).

Table 3: Univariate and multivariate analyses of risk factors for measurement error of sublingual temperature measurements compared to core temperature as measured by axillary temperature.

	Univariate analysis	Multivariate analysis adjusted for age and sex
Male sex	**-0.079 (-0.121 to -0.036)**	**-0.080 (-0.123 to -0.037)**
Age, years	+0.001 (-0.001 to +0.002)	-
Taking beta-blockers	**-0.075 (-0.125 to -0.024)**	**-0.108 (-0.163 to -0.052)**
Currently pregnant*	-0.093 (-0.254 to +0.069)	-
Post menopause*	**+0.121 (+0.042 to +0.200)**	**+0.163 (+0.027 to +0.299)**
Current smokers	**-0.092 (-0.161 to -0.023)**	-0.059 (-0.131 to +0.013)
Current user of smokeless tobacco	**-0.090 (-0.158 to -0.023)**	-0.057 (-0.127 to +0.014)
Had a hot drink within 15 minutes of temperature measurement	**-0.165 (-0.322 to -0.008)**	**-0.161 (-0.318 to -0.005)**
Had a cold drink within 15 minutes of temperature measurement	**-0.111 (-0.157 to -0.064)**	**-0.104 (-0.151 to -0.057)**
Body mass index, kg/m^2	+0.001 (-0.006 to +0.008)	**-**
Room temperature at time of temperature measurement, °C	+0.001 (-0.009 to +0.011)	-
Ambient humidity at the time of temperature measurement, % 1^{st} tertile (19-44) 2^{nd} tertile (45-48) 3^{rd} tertile (49-50)	 **ref** **-0.179 (-0.230 to -0.129)** **-0.180 (-0.229 to -0.131)**	 **ref** **-0.172 (-0.223 to -0.122)** **-0.172 (-0.221 to -0.123)**

Difference defined as sublingual temperature – axillary temperature
Bold text = $p<0.05$

Similarly to the infra-red thermometers, post-menopausal women had a positive measurement error when using the sub-lingual thermometers, with temperature measurements higher than the axillary temperature measurements. In contrast negative measurement error was associated with beta-blocker use, consumption of hot or cold drink within 15 minutes of temperature measurement, and ambient relative humidity at the time of temperature measurement.

Discussion

This is the first study to collect data on the accuracy of commonly used methods of measuring body temperature in a population of patients from an African country and to explore how this measurement error is modified by demographic and environmental exposures. Using the infra-red thermometer, 18% of individuals had a temperature reading that differed by 0.5 °C or more from the axillary temperature, while the corresponding figure for the sublingual thermometer was 17%. These measurement errors were further modified by age, sex, and exposures such as the beta-blocker use, pregnancy, current cigarette smoking, menopause, ambient humidity, and recent consumption of hot or cold drinks.

One of the strengths of this dataset is that it is one of the largest of its kind, with real world data from a busy clinical setting as rather than data collected under laboratory conditions. The broad range of ages, and relatively high proportion of participants who were taking beta-blockers, were pregnant or were post-menopausal allowed us to investigate the impact of these factors on the accuracy of infrared skin and sub-lingual thermometers. As there have been prior concerns that infrared skin thermometers may have increased measurement error in individuals with non-White skin (5), generalising these data to other populations should be done with caution and will ultimately require further studies. These thermometers are widely available and used in Ethiopia, making these data relevant to a country with a population of over 100 million individuals.

The limitations of these data include the fact that we could only collect matched samples from just over 2000 individuals, rather than the planned 10000 participants, due to equipment failure and logistical challenges. However, the relatively small mean measurement error of less than 0.2 degrees Centigrade for both the infra-red skin thermometer and sublingual thermometer temperature measurements compared to axillary temperature provides some confidence that these readings are clinically useful. In addition, we identified several factors that modified measurement error of different thermometers, suggesting that the study had sufficient power despite the decreased number of individuals surveyed.

Many of the factors that modify measurement error for the infra-red skin thermometer (post-menopause, beta-blocker use, pregnancy, current smoking, current smokeless tobacco use, consumption of hot or cold drink within 15 minutes of temperature measurement, body mass index and ambient humidity at time of temperature measurement) may also be associated with vasodilation or vasoconstriction, providing a potential mechanism that may contribute to our observations. If this is the case, it may suggest that infrared skin thermometer temperature measurements should be used with caution in certain groups of patients or in environments with high levels of ambient humidity. It is worth highlighting that the size of the error generated by the infrared skin thermometer in post-menopausal women was relatively large at +0.6 ° Centigrade, and could potentially impair clinical decision-making in this large segment of the population if replicated in further studies. The direction of any temperature measurement error is also important, as under-measurement may delay recognition of increased temperatures, while over-measurement may delay recognition of hypothermia.

Similarly, some of the factors that modify measurement error for sub-lingual thermometers (post-menopause, beta-blocker use, pregnancy, consumption of a hot or cold drink within 15 minutes of temperature measurement, body mass index and ambient percent humidity at the time of temperature measurement) may also be associated with vasodilation or vasoconstriction. However, as the buccal cavity is effectively internal, this explanation is more speculative than that for the infrared thermometer readings, and this is another area that requires further research.

The observation that hot and cold drinks can modify measurement error for both sublingual and infrared skin thermometers may be due to local energy transfer in the mouth for the former or to changes in blood flow from the core to the periphery for the latter. Pregnancy is well recognised to cause circulatory changes, and this observation is consistent with the finding that pregnancy modified temperature measurements made using the infrared skin thermometers but not sub-lingual ones.

The observation that environmental humidity is associated with temperature measurement error for both infrared and sublingual thermometers is novel and worthy of consideration. This was observed in an environment at a high altitude with relatively stable humidity. As the global climate changes, countries in the tropics such as Singapore can experience monthly mean environmental humidity of 93%, with minimum daily humidity of 100% recorded (6). The measurement error of infrared and sublingual thermometers in humid tropical countries is an area that requires further assessment, as estimates suggest that by 2025 the region will host most of the world's population and two-thirds of its children (7).

As many of the risk factors associated with measurement error also modify blood circulation to the skin and extremities, studies are particularly required in patients with high temperatures and sepsis, both of which can be associated with impaired blood circulation and can have a mortality rate of 25% (8). The hypothesis that more severely unwell patients will have higher measurement error for skin and oral temperature measurements is supported by data from emergency department patients from the USA, where over 35% of recorded temperatures differed by 0.5 degrees Centigrade or more (2). As estimates suggest that there are 49 million cases of sepsis and 11 million sepsis-related deaths, representing 20% of all global deaths (9), this is an area where more accurate clinical monitoring of temperature has the potential to make a substantial improvement to global mortality. Similar to concerns about greater measurement error of oxygen saturation measurements obtained using pulse oximeters in individuals with darker skin tones (10), these findings raise wider questions about the validation of commonly used medical devices in African populations.

Conclusions

In summary, to the best of our knowledge, these data represent the first study of its kind to explore risk factors for measurement error across different methods of measuring temperature. As such, it provides a basis for further studies across diverse clinical populations to explore how exposures that modify peripheral circulation may introduce measurement error into temperature readings.

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Conflict of interest: The authors have no conflict of interest to declare.

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References

1. Johnson JM, Kellogg DL. Chapter 11 - Skin vasoconstriction as a heat conservation thermoeffector. In: Romanovsky AA, editor. Handbook of Clinical Neurology. 156: Elsevier; 2018. p. 175-92.

2. Bijur PE, Shah PD, Esses D. Temperature measurement in the adult emergency department: oral, tympanic membrane and temporal artery temperatures versus rectal temperature. Emerg Med J. 2016;33(12):843-7.
3. GST Corporation. GST Corporation Products. https://wwwmedicade/vis-content/event-medica2025/exh-medica20253033335/MEDICA-2025-GST-Corporation-Limited-Paper-medica20253033335-2CpuxwtwSPaMCUvAOQ7wQwpdf (accessed 14/1/2026). 2025.
4. Guangdong Yuefeng Bakery Co. Non Contact Digital Forehead Infrared Thermometer in Household Body Temperature (STBH). https://yuefengbakeryenmade-in-chinacom/product/fXFxWPVjAbph/China-Non-Contact-Digital-Forehead-Infrared-Thermometer-in-Household-Body-Temperature-STBH-html (accessed 14/1/2026). 2025.
5. Bhavani SV, Wiley Z, Verhoef PA, Coopersmith CM, Ofotokun I. Racial Differences in Detection of Fever Using Temporal vs Oral Temperature Measurements in Hospitalized Patients. JAMA. 2022;328(9):885-6.
6. Meteorological Service Singapore. Historical extremes: relative humidity. https://wwwweathergovsg/climate-historical-extremes-humidity/ (accessed 14/1/2026). 2025.
7. United Nations. International day of the tropics. https://wwwunorg/en/observances/tropics-day (accessed 14/1/2026). 2025.
8. Dulhunty JM, Brett SJ, De Waele JJ, Rajbhandari D, Billot L, Cotta MO, et al. Continuous vs Intermittent β-Lactam Antibiotic Infusions in Critically Ill Patients With Sepsis: The BLING III Randomized Clinical Trial. JAMA. 2024;332(8):629-37.
9. Rudd KE, Johnson SC, Agesa KM, Shackelford KA, Tsoi D, Kievlan DR, et al. Global, regional, and national sepsis incidence and mortality, 1990–2017: analysis for the Global Burden of Disease Study. The Lancet. 2020;395(10219):200-11.
10. 1Valley TS, Fogarty AW. Pulse oximetry in people with darker skin tones. BMJ. 2026;392:s37.