Are all thermometers equal? A study of three infrared thermometers to detect fever in an African outpatient clinic

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Infrared thermometry has certain advantages over traditional oral thermometry including quick, non-invasive administration and an absence of required consumables. This study compared the performance of tympanic, temporal artery and forehead contactless thermometers with traditional oral electronic thermometer in measuring temperature in outpatients in a Nigerian secondary care hospital. A convenience sample of 100 male and 100 female adult patients (Mean age= 38.46 years, SD= 16.33 years) were recruited from a secondary care hospital in Kano, Nigeria. Temperature measurements were taken from each patient using the tympanic, temporal artery and contactless thermometers and oral electronic thermometer. Data was analyzed to assess bias and limits using scatterplots and Bland-Altman charts while sensitivity analysis was done using ROC curves. The tympanic and temporal artery thermometers systematically gave higher temperature readings compared to the oral electronic thermometer. Contactless thermometer gave lower readings compared to the oral electronic thermometer. Temporal artery thermometer had the highest sensitivity (88%) and specificity (88%) among the three infrared thermometers. Contactless thermometer showed a low sensitivity of 13% to detect fever greater than 38^{o}C. Our study shows that replacing oral thermometers with infrared thermometers must be done with caution despite the associated convenience and cost savings.

Title Page

Running Heading: Fever Detection in Nigeria

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Abstract and key terms

Infrared thermometry has certain advantages over traditional oral thermometry including quick, non-invasive administration and an absence of required consumables. This study compared the performance of tympanic, temporal artery and forehead contactless thermometers with traditional oral electronic thermometer in measuring temperature in outpatients in a Nigerian secondary care hospital. A convenience sample of 100 male and 100 female adult patients (Mean age= 38.46 years, SD= 16.33 years) were recruited from a secondary care hospital in Kano, Nigeria. Temperature measurements were taken from each patient using the tympanic, temporal artery and contactless thermometers and oral electronic thermometer. Data was analyzed to assess bias and limits using scatterplots and Bland-Altman charts while sensitivity analysis was done using ROC curves. The tympanic and temporal artery thermometers systematically gave higher temperature readings compared to the oral electronic thermometer. Contactless thermometer gave lower readings compared to the oral electronic thermometer. Temporal artery thermometer had the highest sensitivity (88%) and specificity (88%) among the three infrared thermometers. Contactless thermometer showed a low sensitivity of 13% to detect fever greater than 38ºC. Our study shows that replacing oral thermometers with infrared thermometers must be done with caution despite the associated convenience and cost savings.

Key words: Infrared thermometer, contactless, bias, fever detection

1. Introduction

1.1. Temperature as a Vital Sign

Temperature is a vital sign taken during every patient encounter, as fever - generally defined as a temperature above 38°C– is a sign that the body's normal thermoregulation is altered. The most common reason for fever is a microbial infection of the body. Therefore, body temperature measurements (BMTs) have been instrumental for infectious disease surveillance, as evidenced in the recent epidemics such as SARS, H1N1, Ebola and COVID-19, where there was great need for effective, efficient outbreak monitoring and control [7,20,22].

Temperature screening at airports was encouraged by West African public health authorities during the 2014-2016 Ebola epidemic to control the transmission of the virus. These temperature screenings allowed the prevention of those who might be febrile from travelling, and thus were part of a co-ordinated attempt to limit the transmission of the virus [8,26]. This kind of mass transport, community-based, and even at-home temperature screening has also been integral to global containment efforts during the current COVID-19 pandemic [16,27].

There are several methods of taking body temperature depending on the health care setting, patient acuity, health care provider partiality, patient preference, accuracy required, and costs involved. Core body temperature can be measured by invasive methods such as esophageal thermometry, pulmonary artery thermometry, and rectal thermometry. Rectal temperature measurement in particular has been seen as the gold standard for accurate temperature measurement [1,13,24,28]. However, it has the disadvantages accompanying invasive procedures including their associated risks, patient discomfort, high costs and chance of infection. Therefore, non-invasive thermometry is the preferred method of measuring patient temperature in most clinical settings. This is also true when attempting to monitor and control infectious diseases in developing countries, where rapid, less-invasive screening processes tend to be favoured by both the public and their policy makers even in non-clinical settings [1,14]. Non-invasive thermometry is even more appealing during infectious pandemics as frontline workers can collect temperature readings without physical contact with the patient, thus reducing the risk of disease transmission.

1.2. Non-invasive Thermometry

Temperature can be measured non-invasively by methods that require contact or no contact with the body surface. Methods that require contact include oral thermometers, tympanic thermometers, temporal artery thermometers (TAT), and axillary thermometers. Lawson *et al*. [18] explicitly state that oral measurements are one of the most accurate and precise non-invasive body temperature measurements. However, accurate oral temperature measurements can be influenced by improper probe placement in the mouth by clinicians, as well as the ingestion of hot or cold liquids by patients. Oral thermometry is also contraindicated in unconscious and delirious patients [18,21]. In addition, because probe covers and frequent alcohol swabs are crucial for reducing cross-infection when using oral thermometers, these consumables can add to clinic costs and also add workload to already overwhelmed staff in outbreak-prone areas [4,15,21].

Tympanic infrared thermometers are noninvasive, inexpensive, quick and need no consumables. But it can be difficult to position, and have the associated risk of membrane perforation when administered inadequately in both active patients, sedated patients, and those with ear infections [1,24]. Some studies have shown that tympanic infrared thermometry measurements have increased variability compared to oral and/or rectal measurements [1,18]. It is also important to be sensitive to patients who may not feel comfortable removing cultural head coverings, and thus preclude adequate access to the tympanic membrane.

Temporal artery thermometers are noninvasive infrared thermometers that measure temperature along the temporal artery on the forehead[19]. TAT has many clinical benefits including the fact that it poses minimal risk of infection, limited risk of injury (i.e. perforation/ discomfort), and it allows for an easily accessible BTM that meets with little patient resistance [1,15,24,25]. Further, many studies comparing the utility and accuracy of TAT in comparison to rectal and oral thermometry, showed that TAT can result in time-savings for clinicians who work with pediatric populations [12], but that TAT also tends to underperform [1,3,23].

1.3. Forehead contactless infrared thermometry

Among the various infrared thermometry techniques, the one with the least amount of direct risk to patients during measurement is contactless infrared thermometry. In this method an infrared sensor is placed a few centimeters away from a person’s body and the temperature is calculated based on infrared emissions from the body. Such infrared contactless thermometers came into widespread use during the Ebola outbreak. These are now commonly used in settings as varied as clinics, hospitals, shopping malls, and airports to screen for fever worldwide. Contactless thermometry provides quick, non-invasive temperature measurements without requiring frequent sterilization or consumables [12]. Forehead contactless infrared thermometry is appealing in terms of its low impact on clinician workflow as these thermometers provide quick, non-invasive BTMs that can be easily measured without undressing the patient [9,11,12]. Though patients and clinicians may show partiality to this non-invasive and contactless BTM method, recently, a variability in the reliability and accuracy of forehead contactless infrared thermometry was observed [5]. In addition, a high false-positive rate of contactless infrared thermometry during mass fever screening in children has been highlighted [23].

1.4. Objective

Infrared contact and contactless thermometers are rapidly gaining use in clinics and hospitals across Africa. There is substantial evidence supporting the use of infrared contact thermometers in clinical settings. However, as a relatively new entrant into thermometry, contactless infrared thermometry does not have a corpus of evidence to support its routine clinical use as a replacement for other established methods. Therefore, the purpose of this study was to compare the accuracy and utility to diagnose fever of three infrared thermometers (tympanic, temporal artery and contactless) against a standard oral digital thermometer in adult outpatients in a Nigerian secondary care hospital.

2. Materials and Methods

2.1. Participants

A convenience sample of 200 adult outpatients (100 male and 100 female) were recruited over four days in April 2019 from the general outpatient department of a secondary care hospital in Kano, Northern Nigeria. Ethics approvals were obtained from the Health Research Ethics Committee of the Kano State Ministry of Health, Nigeria (MOH/Off/797/T.I/1199, MOH/Off/797/T.I/1208).

Inclusion Criteria:
-Adult patients over the age of 18 who are able and willing to give verbal informed consent to participate in the study.

Exclusion Criteria:
-Patients with altered consciousness
-Patients in distress
-Patients with hemodynamic instability
-Patients with malformation of ears
-Male patients who do not wish to remove their caps
-Female patients who do not wish to remove their head coverings
-Any patient who objects to any of the four methods of temperature measurement

2.2. Apparatus and Materials

The following thermometers were used:

- Temporal Artery (TAT 5000, Exergen)
- Contactless (TriTemp, Trimedika)
- Tympanic (Smart Ear, Kinsa)
- Oral digital thermometer (SureTemp Plus 690, Welch Allyn).

2.3. Procedure

2.3.1. Clinical Study

The team leader logged the ambient temperature at the start of the study and every 30 minutes thereafter. Informed verbal consent was obtained and the patient's demographic information was captured using Microsoft Excel®.

If the patient was wearing a headcap or head covering, the patient was asked to remove them for the duration of the temperature measurement. The nurse then waited 5 minutes before proceeding to wipe the forehead of the patient with a disposable paper towel. The nurse then took the temperature measurements. Only a single measurement was taken per device. All four methods of temperature measurements were done consecutively in the same participant within a span of 5 minutes. The sequence of the thermometry (Oral→tympanic→temporal artery→contactless) was cycled with each participant so as not to introduce bias. Any patient noted to have a temperature greater than 38°C was directed to the duty nurse. Each thermometer was cleaned using disinfectant alcohol wipe after each use.

2.3.2. Statistical Analysis

Microsoft Excel and STATA 13 were used for statistical analysis. Statistical significance was set at a p-value less than 0.05 and 95% confidence interval. Receiver operating characteristics were charted to assess sensitivity, specificity, positive predictive value and negative predictive value for different thermometry techniques in comparison with oral thermometry. Sensitivity and specificity of the three infrared thermometers to detect fever, as defined by an oral temperature greater than or equal to 38ºC, were calculated.

3. Results

Half the patients were male and half were female. Ages of the patients ranged between 18 and 82 years (Mean age = 38.46, SD= 16.33). Eight (4%) of the two hundred patients had an oral temperature of 38℃ or higher. The average ambient temperature was 31.5℃. Figure 1 shows the scatterplots of tympanic, temporal artery and contactless thermometers. Position of the data points in relation to the line of equality (black) gives an indication of the bias of each measurement method. Both tympanic and temporal artery thermometers had similar bias but contactless thermometer had the opposite bias as evident in the scatterplots. True positives, false positives, true negatives and false negatives are indicated as the four quadrants created by the intersection of the 38℃ (fever threshold) lines.

Figure 1.

The degree of agreement of the thermometers and the reference standard was also analyzed using Bland Altman plots. (Figure 2). This is a better way to demonstrate bias in measurement methods[6].

Bland Altman plots can indicate mean bias and any relationship between the discrepancies and the reference value. The blue dashed lines represent the mean difference in temperature and dotted blue lines represent the 95% confidence interval of the mean difference. The mean difference in temperature measurements between infrared thermometers and oral thermometers, as well as their 95% limits of agreement can be seen in Table 1.

Figure 2.

Table 1.

Tympanic and TA thermometers had negative bias of 0.24 and 0.23 respectively compared to the reference thermometer. This signifies that the tympanic and temporal artery thermometers systematically gave higher temperature readings compared to the oral electronic reference thermometer. Contactless thermometer, however, had a positive bias of 0.06, systematically giving lower readings compared to the oral electronic thermometer.

Table 2.

In clinical practice, the ability of a thermometer to accurately detect fever is perhaps more important than its bias compared to a reference standard. We calculated the sensitivity, specificity, negative and positive predictive values of the three infrared thermometers in comparison to the oral thermometer. As shown in table 2, our study showed good sensitivity and specificity for forehead and tympanic infrared thermometers. Temporal artery thermo
meter had the highest sensitivity (88%) and specificity (88%) among the three infrared thermometers. The contactless thermometer showed a sensitivity of 13% and specificity of 96%. Positive predictive values for all thermometers were low, ranging between 13% and 23% while the negative predictive values ranged between 96% and 99%. Tympanic and temporal artery temperature readings had moderate correlation with or
al temperature as indicated by the Spearmann correlation coefficient while contactless temperature had very low correlation with oral temperature.
Finally, we plotted the receiver operating characteristic curves for the three thermometers to graphically present the variation in sensitivities and specificities, shown in figure 3. An ROC curve plots true positive rate against false positive rate for different diagnostic cut-offs. Temporal artery thermometer had the highest area under the curve of 0.87, followed by tympanic with an AUC of 0.78. Contactless thermometer had an AUC of 0.62.

Figure 3.

4. Discussion

The goals of our study were to investigate the accuracies of various infrared thermometers, and additionally, to estimate their ability to detect fever in an outpatient clinic setting. We accomplished this by determining the bias of three infrared thermometers in comparison to oral thermometers and conducting sensitivity analyses. We chose an oral digital thermometer to be the reference thermometer as this has been the standard of care in most outpatient clinical settings. We wanted to evaluate newer, more convenient thermometers that are relevant in low resource outpatient settings against a standard of care comparator.

Bias

Scatter plots and Bland-Altman charts showed that all three infrared thermometers had bias in comparison to the reference oral thermometer in our study. Tympanic and temporal artery thermometers had negative bias while the contactless thermometer had a positive bias. The absolute value of the bias was smallest for the contactless thermometer in our study.

A comparison of oral and temporal artery thermometers against esophageal thermometry found smaller but positive bias for the temporal artery thermometer among patients in surgery [10]. An analysis of axillary and temporal artery thermometer compared to oral thermometer in pre and post operative patients found smaller but negative bias for temporal artery thermometer [4]. A comparison of contactless, tympanic and temporal artery thermometer with reference to rectal thermometer in pediatric inpatients found no bias for temporal artery thermometer, and positive bias for tympanic as well as contactless thermometer [1]. Comparison of tympanic and temporal artery thermometers with bladder reference thermometers showed smaller and a negative bias for temporal artery thermometers among postoperative patients [17]. Differing results between these studies indicate that bias is likely dependent not only on the type of reference device and make/model of index device, but also on the patient population and the clinical setting.

Correlation coefficients

We found low to moderate correlation between the infrared thermometer readings and oral thermometer readings as indicated by Spearman correlation coefficients. The lowest correlation coefficient of 0.15 was for the contactless thermometer. A comparison of rectal and temporal artery temperature among children under three years of age at a hospital reported Spearman's correlation coefficient of 0.86 [3]. Spearman correlation coefficient for tympanic thermometer among hospitalized adult patients was 0.93 when compared to nasopharyngeal reference thermometer [2]. Lin's concordance correlation coefficient was 0.53 for temporal artery and 0.34 for tympanic thermometers among postoperative patients [17].

Sensitivity analysis

In an outpatient clinical setting, a thermometer is primarily used to test for the absence or presence of fever. The ability to accurately detect fever is indicated by the positive and negative predictive values of a thermometer. The predictive value of a thermometer is in turn determined by its sensitivity and specificity, as well as the prevalence of fever in the patient population. An ideal diagnostic device will have sensitivity and specificity of 100% meaning it will correctly identify every positive and negative case. But in reality, sensitivity and specificity of a diagnostic device are often a trade-off with each other. As the sensitivity increases, the device will correctly identify every positive case, but often sacrifice specificity, which is the ability to correctly identify every negative case. As sensitivity and specificity are fixed for a particular diagnostic device, the positive predictive value increases and negative predictive decreases as prevalence increases.

The prevalence of fever in our population was 4%. Sensitivity was highest for the temporal artery thermometer (88%) while specificity was highest for the contactless thermometer

(96%). Contactless thermometer had a very low sensitivity of 13%. This means that the contactless thermometer would only detect 13 out of 100 patients with fever.

Negative predictive value was more than 95% while positive predictive value was lower than 25% for all thermometers in our study population. The negative predictive value is arguably the most important clinical performance characteristic of any diagnostic device used in disease screening. Failing to diagnose fever in febrile patients can cause adverse outcomes such as worsening of disease severity, spreading of the infection to others, higher costs of eventual treatment and possibly even death. These adverse events are more likely in low-resource and rural settings where access to treatment is limited. For a hypothetical fever prevalence of 20% - as can happen in an infectious disease epidemic or a hospital inpatient unit - the negative predictive value of the contactless thermometer would drop to an unacceptable 80%, missing almost one in every five febrile patients. The tympanic and forehead thermometers would maintain their negative predictive values of more than 93% even with a fever prevalence of 20%.

A comparison of tympanic, contactless and temporal artery thermometers in pediatric inpatients found sensitivities of 22, 27 and 44 respectively, while the negative predictive values for fever were 94%, 92% and 96% respectively [1]. Temporal artery thermometer also had sensitivity, specificity and negative predictive value of 83%, 86% and 97% among infants in an emergency department [9]. Tympanic thermometers had sensitivity of 83%, specificity of 100% and negative predictive value of 93% among ICU patients [2].

ROC curves can be useful to determine overall accuracy of a diagnostic device. Higher area under the ROC curve is preferred with an ideal diagnostic device having an area under the curve (AUC) of 1. We saw the best overall accuracy for the temporal artery thermometer with an AUC of 0.87, while the least accurate was the contactless thermometer with an AUC of 0.62. For context, tossing an unbiased coin as a diagnostic device to diagnose fever in a patient should give an AUC of 0.5.

One image that came to define the 2014-2016 Ebola outbreak in West Africa was that of a contactless infrared thermometer pointed at a patient's forehead. Containment efforts of the virus depended on the conspicuous visibility of its incredibly severe symptoms and its transmissibility only from those who were visibly ill. On the other hand, the highly transmissible COVID-19 traveled the world less conspicuously and thus, necessitated temperature screenings in non-clinical spaces like airports, stores, and even restaurants. It is debatable how much these temperature screenings help with limiting the spread of infectious disease outbreaks.

Notwithstanding, an increasing number of clinics and hospitals are choosing to switch from traditional thermometry to infrared thermometry. Though patients and clinicians may show partiality to this non-invasive and contactless BTM method, our study showed that the forehead contactless thermometer had very poor sensitivity to detect fever. Therefore, if in common use, contactless infrared thermometers may actually result in large numbers of febrile patients being underdiagnosed. Further studies are warranted to determine the precise cut-off temperatures for various thermometers in order to minimize the chances of false negative readings when screening for fever. Considerations must be made to balance accuracy, patient comfort, clinician efficiency and administrative costs. Additionally, considering the limited resources and operating budgets, it would be beneficial to evaluate the cost implications when choosing a particular mode of thermometry in a low-resource clinic or hospital setting. Our study recommends that replacing oral thermometers with infrared thermometers must be done with caution despite the associated convenience and cost savings.

5. Conflict of interest

No benefits in any form have been received from a commercial party related directly or indirectly to the subject of this manuscript.

6. Acknowledgments

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References

1. Allegaert, K., K. Casteals, I.V. Gorp, and G. Bogaert. Tympanic, infrared skin and temporal artery scan thermometers compared with rectal measurement in children: A real-life assessment. *Cur. Therap. Res.* 76: 34-38, 2014.
2. Asadian, S., A. Khatony, G. Moradi, A. Abdi, and M. Rezali. Accuracy and precision of four common peripheral temperature measurement methods in intensive care patients. Med Devices: *Evid. and Res*. 9: 301-308, 2016.
3. Bahorski, J., T. Repasky, D. Ranner, A. Fields, M. Jackson, L. Mailtry, K. Pierce, and M. Sandell. Temperature measurement in pediatrics: A comparison of the rectal methods versus the temporal artery method. *J. Perianesth.Nurs*. 27(3): 243-247, 2012.
4. Barringer, L.B., C.W. Evans, L. L. Ingram, P. P. Tisdale, S. P. Watson, and J. K. Janken. Agreement between temporal artery, oral and axillary temperature measurements in the perioperative period. *J. Perianesth.Nurs*. 26(3): 143-150, 2011.
5. Berkosy, E. A., O. Bag, S. Yazici, and T. Celik. Use of noncontact infrared thermography to measure temperature in children in a triage room. *Med*. 97(5), 2018.
6. Bland, J. M., and D. G. Altman. Measuring agreement in comparison studies. *Stat. Meth. Med. Res*. 8(2): 135-160, 1999.
7. Bordonaro, S.F., D. C. McGillicuddy, F. Pompei, D. Burmistrov, C. Harding, and L. D. Sanchez. Human temperatures for syndromic surveillance in the emergency department: data from the autumn wave of the 2009 swine flu (H1N1) pandemic and a seasonal influenza outbreak. *BMC Emer. Med.* 16(1), 2016.

8. Brown, C. M., A. E. Aranas, G. A. Benenson, G. Brunette, M. Cetron, T. H. Chen, N. J. Cohen, P. Diaz, Y. Haber, C. R. Hale, K. Holton, K. Kohl, A. W. Le, L. D. Rotz, J.Tappero, F. M. Washburn, J. Watkins, N. Pesik, and Centers for Disease Control and Prevention (CDC). Airport exit and entry screening for Ebola. 63(50): 1212, 2014.
9. Callanan, D. Detecting fever in young infants : Reliability of perceived, pacifier, and temporal artery. *Ped. Emerg. Care*. 19(4): 01-04, 2001.
10. Calonder, E. M., S. Sendelbach, J. S. Hodges, C. Gustafson, C. Machemer, D. Johnson, and L. Reiland. Temperature measurement in patients undergoing colorectal surgery and gynecology surgery: a comparison of esopharyngeal core, temporal artery, and oral methods. *J. Perianesth.Nurs*. 25(2): 71-8, 2010.
11. Carleton, E., B. Fry, A. Mulligan, A. Bell, and C. Brossart. Temporal artery thermometer use in the prehospital setting. *CJEM*. 14(01): 7-13, 2012.
12. Chiappini, E., S. Sollai, R. Longhi, L. Moradini, A. Laghi, C. E. Osio, M. Persiani, S. Lonati, R. Picchi, F. Bonsignori, F. Mannelli, L. Galli, and M. deMartino. Performance of non-contact infrared thermometer for detecting febrile children in hospital and ambulatory settings. *J.Clin.Nurs*. 20: 1311-1318, 2011.
13. Geijer, H., R. Udumyan, G. Lotise, and Y. Nulsagard. Temperature measurements with a temporal scanner: systematic review and meta-analysis. *BMJ open*. 6(3), 2016.
14. Hausfater, P., S. Defrenne, P. Bonnet, and B. Riou. Cutaneous infrared thermometry for detecting febrile patients. *Emerg. Infec. Dis.* 14(8): 1255-1258, 2008.

15. Hayes, K., A. Shephard, A. Cesarec, and R. Likic. Cost minimisation analysis of thermometry in two different hospital systems. *Postgrad. Med. Jour.* 93(1104):603-606, 2017.
16. Jernigan, D. B., and CDC COVID- 19 Response Team-Update: Public health response to the coronavirus disease outbreak-United States. *MMWR Morb. Mortal Wkly Rep*. 69(8):216-219, 2020.
17. Langham, G. E., A. Maheshwari, K. Contrera, J. You, E. Mascha, and D. J. Sessler. Non-invasive temperature monitoring in postanesthesia care units. *Anesthesiology*. (111): 90-96, 2009.
18. Lawson, L., E. J. Bridges, I. Ballou, R. Eraker, S. Greco, J. Shively, and V. Sochulak. According and precision of non-invasive temperature measurement in adult care patients. *Am. J. Crit Care*. 16(5): 489-96.
19. Myny, D., J. D. Waele, T. Defloor, S. Blot, and F. Colardyn. Temporal scanner themometry: A new method of core temperature estimation in ICU patients. Scottish Med. J. 50(1):15-18, 2005.
20. Ng, D. K., C. H. Chan, R. S. Lee, and L. C. Leung. Non-contact infrared thermometry temperature measurement for screening fever in children. *Annals of Trop. paed*. 25 (4): 267-275, 2005.
21. Pappas, M. Understanding the different methods for taking a temperature. *NASN Sch. Nur.* 27(5): 254-255, 2012.
22. Plaza, J. J. D., N. Hulak, Z. Zhumadilar, and A. Akilzhanova. Fever as an important resource for infectious diseases research, *Intra. and Rare Dis. Res*. 5(2): 97–102, 2016.

23. Reynolds, M., L. Bonham, M. Gueck, K. Hammond, C. Rodel, S. Smith, S. Sukosd, and M. craft. Are temporal artery temperature measurement in paediatrics ED patients?. *Jour. of Emerg. Nur*. 40(1): 45-50, 2014.
24. Sandlin, D. New Product Review: Temporal artery thermometry. *J. Perianesth.Nurs*. 18(6): 419-421, 2003.
25. Titus, M. O., T. Husley, J. Heckman, and J. D. Losek. Temporal artery thermometry utilization in pediatric emergency care. *Clin. Paed.*48(2): 190-193, 2008.
26. Wickramage, K. Airport entry and exit screening during the ebola virus disease outbreak in Sierra Leone. *BioMed Res. Intern.* 2019.
27. Wright, W. F. Why temperature screening for coronavirus disease 2019 with noncontact infrared thermometers does not work. *open forum infectious diseases*. Oxford University Press, 2020.
28. Yang, W. C., H. T. Kuo, C. H. Lin, K. H. Wu, Y. J. Chang, C. Y. Chen, and H. P. Wu. Tympanic temperature versus temporal temperature in patients with pyrexia and chills. *Medicine*. 95(44), 2016.

Table 1 (on next page)

Table 1. Bias of Infrared Thermometers Compared to Oral Electronic Thermometer

Table 1.

Bias of Infrared Thermometers Compared to Oral Electronic Thermometer

	Tympanic	TA	Contactless
Oral – Infrared bias (ºC)	-0.24	-0.23	+0.06
95% limits of agreement of bias (ºC)	-0.97 to 0.49	-0.8 to 0.34	-0.56 to 0.69

Table 2(on next page)

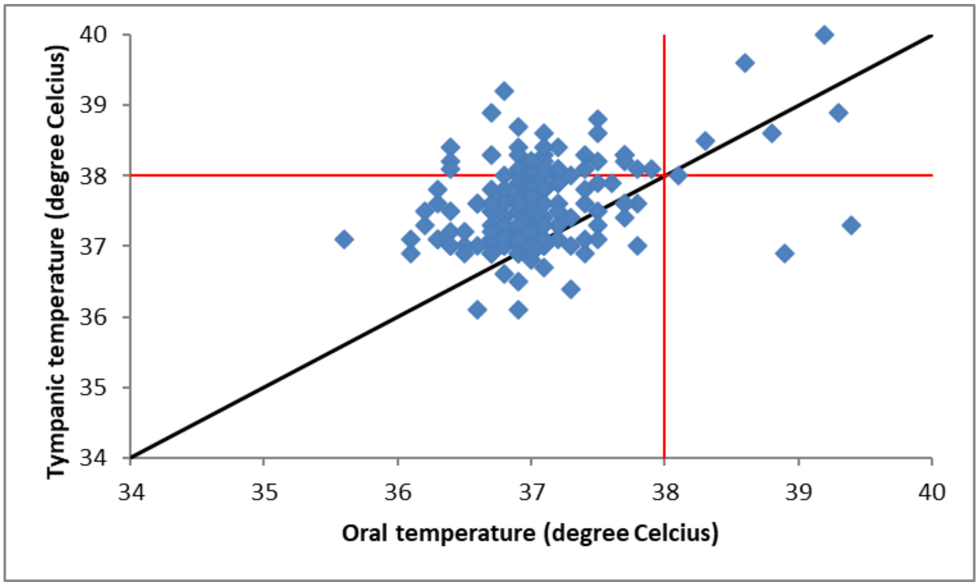
Table 2. Thermometer indices

Table 2. Thermometer Indices

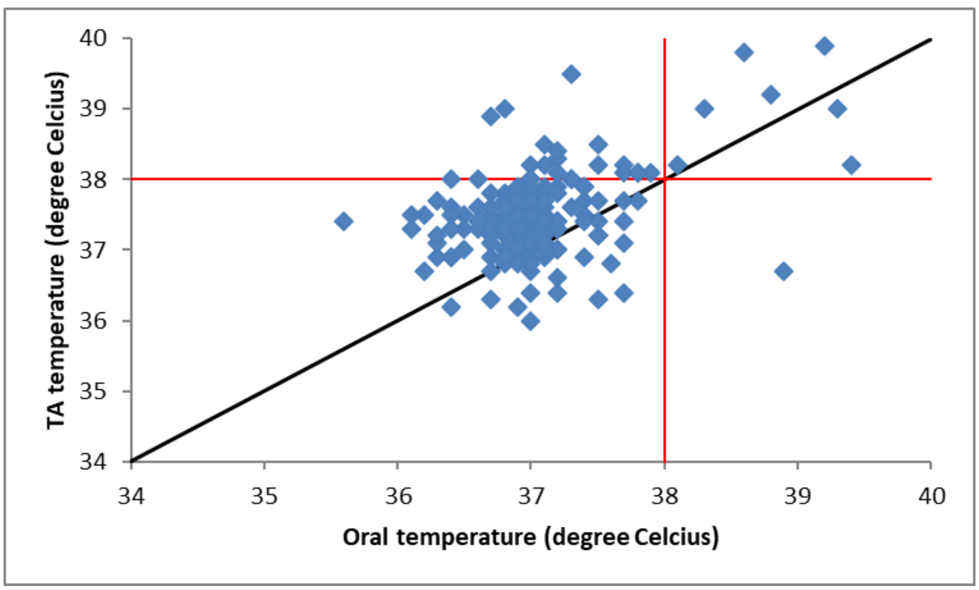
	Spearman Correlation coefficient	Sensitivity	Specificity	PPV	NPV	ROC AUC
Tympanic	0.31	0.75	0.79	0.13	0.99	0.78
TA	0.28	0.88	0.88	0.23	0.99	0.87
Contactless	0.15	0.13	0.96	0.13	0.96	0.62

Figure 1(on next page)

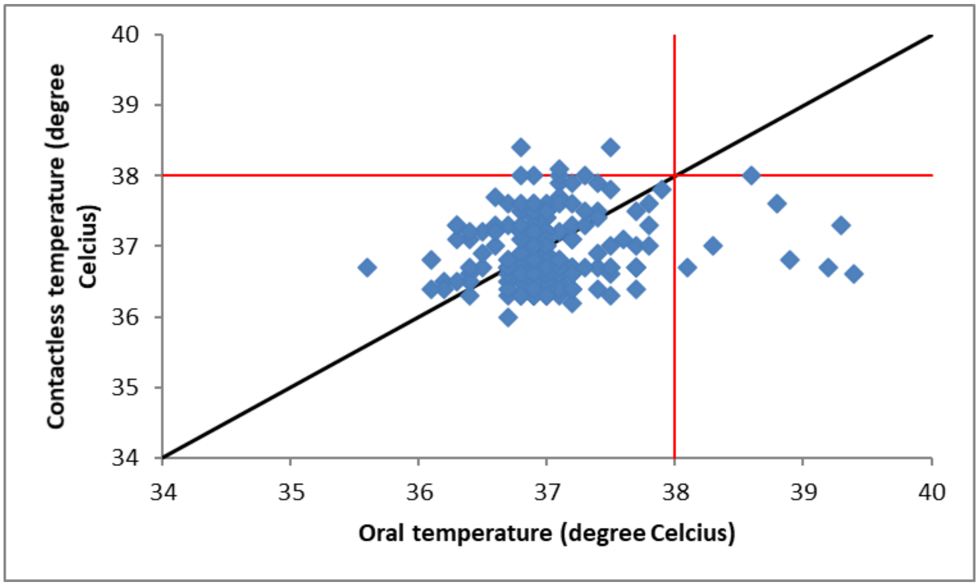
Figure 1. Scatter plots of tympanic, temporal artery (TA) and contactless thermometers



a) Oral temperature Vs tympanic temperature



b) Oral temperature Vs temporal artery (TA) temperature



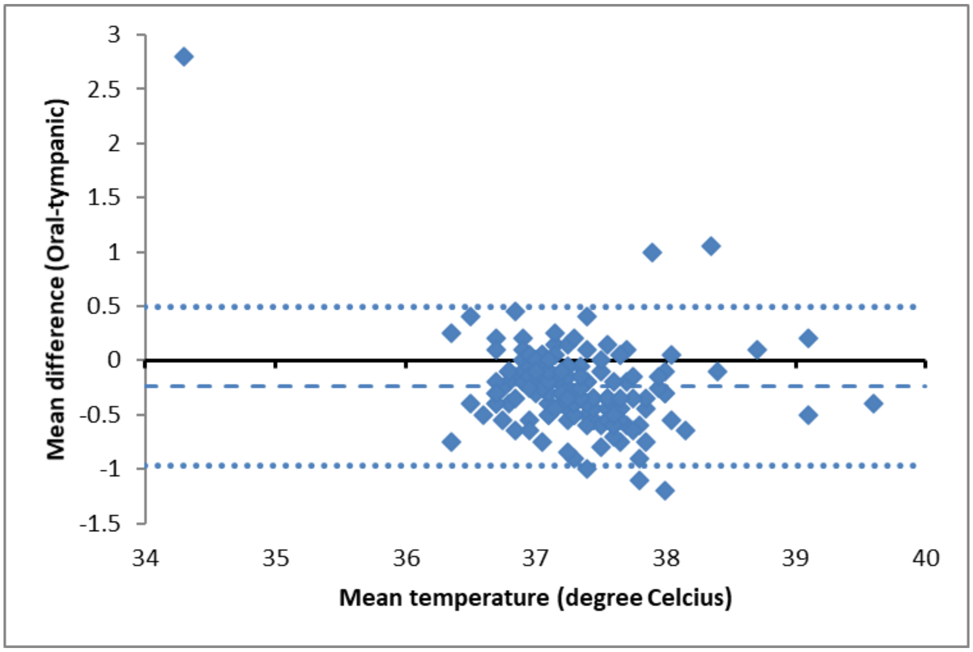
c) Oral temperature Vs forehead contactless temperature

Figure 1. Scatter plots of tympanic, temporal artery (TA) and contactless thermometers

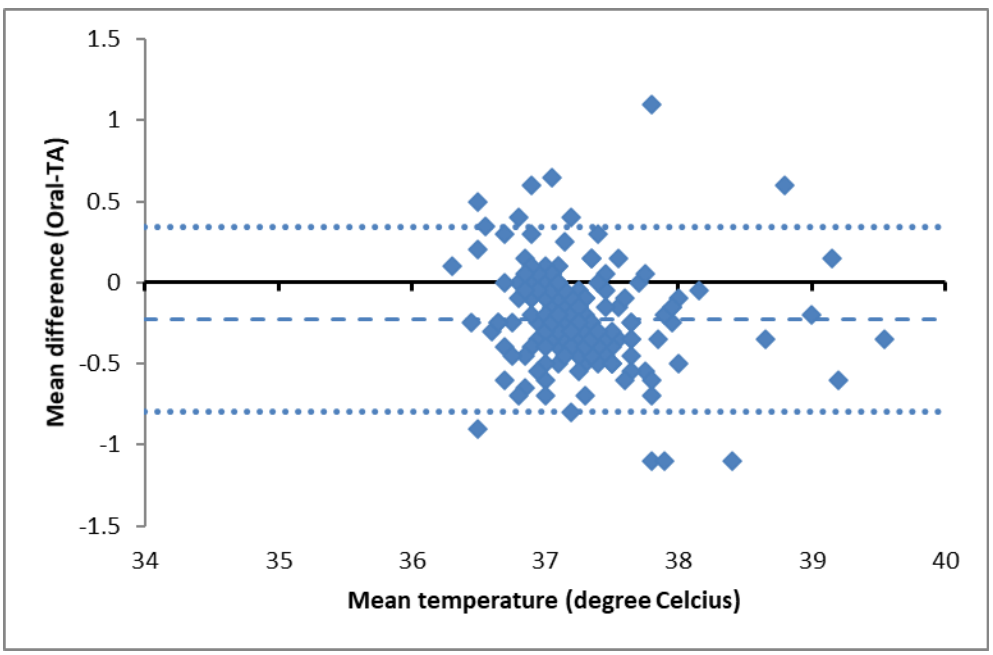
Figure 2 (on next page)

(on next page)

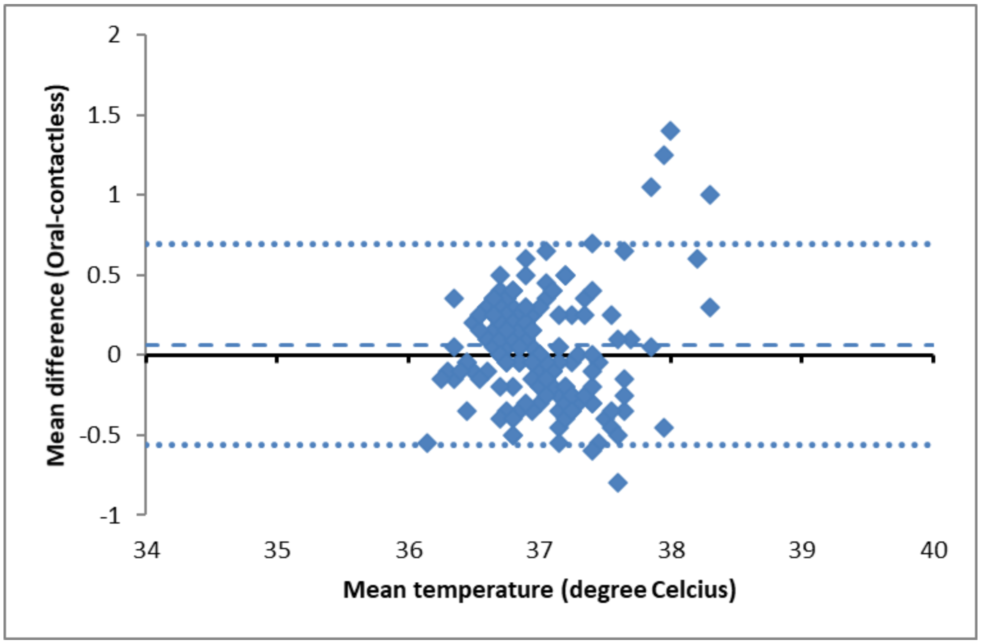
Figure 2. Bland-Altman plots of tympanic, temporal artery (TA) and contactless thermometers



a) Tympanic thermometer



b) Temporal artery (TA) thermometer



c) Forehead contactless thermometer

Figure 2. Bland-Altman plots of tympanic, temporal artery (TA) and contactless thermometers

Figure 3

Figure 3. Receiver operating characteristics of three infrared thermometers

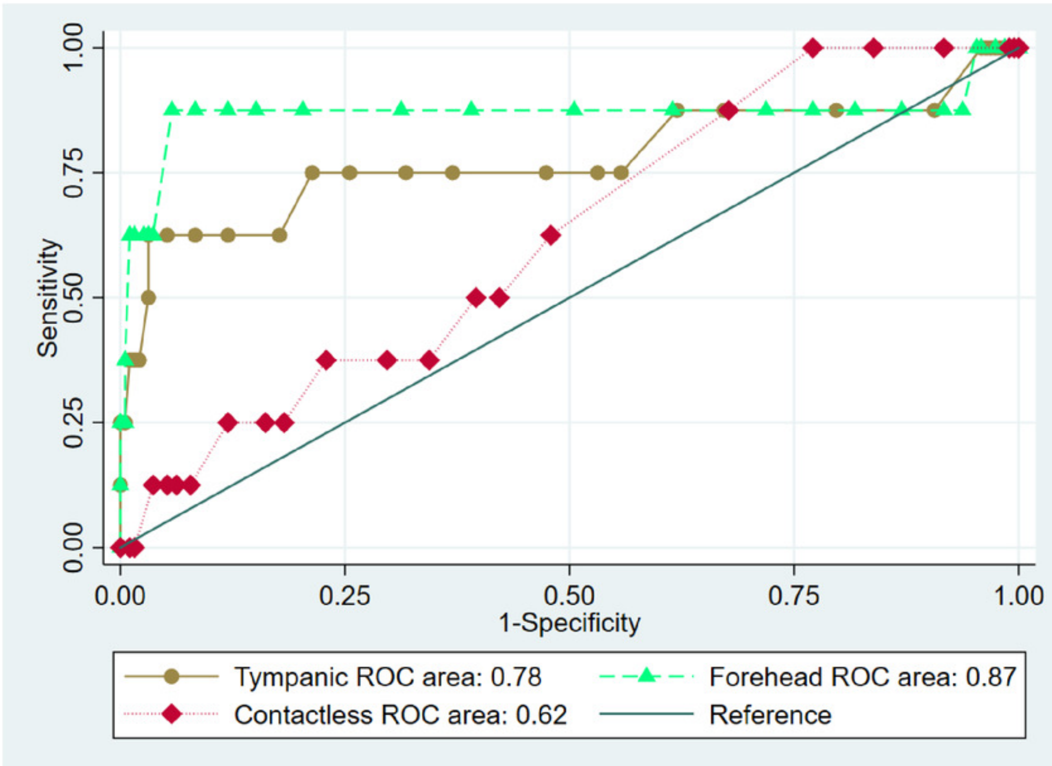


Figure 3. Receiver operating characteristics of three infrared thermometers