Temperature Measurements

Comparison of different thermometer types for patients with cancer

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BACKGROUND: Accurate temperature measurement in patients with cancer is critical. Many patients are neutropenic; therefore, fever represents an oncologic emergency, and, in many cases, it can be the only indication of a life-threatening infection. Although oral thermometers most closely represent true core temperature, patients may have barriers to oral thermometry.

OBJECTIVES: The purpose of this study was to assess the accuracy of two alternative, noninvasive thermometers (tympanic and temporal artery) by comparing them to an oral thermometer.

METHODS: A method-comparison study design was used. Each participant received three temperature measurements. The dependent variable was the difference in temperature between the test thermometers and the oral thermometer.

FINDINGS: The results suggest that neither of the test thermometers accurately represented core temperature, particularly in febrile patients. Both the tympanic and temporal artery thermometers became less accurate as oral temperature increased.

KEYWORDS
oral thermometer; tympanic; temporal artery; temperature; measurement

DIGITAL OBJECT IDENTIFIER
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TEMPERATURE MONITORING IS AN IMPORTANT MECHANISM for detecting fevers during treatment for cancer (Polovich, Olsen, & LeFebvre, 2014). Patients with cancer often experience neutropenia as a result of treatment, and fever may be the first sign of a potentially life-threatening infection, such as sepsis (Mason et al., 2015). For this reason, fever is considered an oncologic emergency, making accurate temperature measurement essential.

The most accurate measure of body temperature is core temperature, which can be measured with invasive devices, such as pulmonary artery catheters and bladder probes (Niven et al., 2015; Opersteny et al., 2017). Core temperature measures are common in critical care settings; however, in other areas, noninvasive alternatives are necessary (Kimberger, Cohen, Illievich, & Lenhardt, 2007). Nondisposable electronic oral thermometers are considered to most closely approximate core temperatures and are widely regarded as the gold standard of noninvasive temperature monitoring (Giuliano, Scott, Elliot, & Giuliano, 1999; Hooper & Andrews, 2006; Jefferies, Weatherall, Young, & Beasley, 2011; Mason et al., 2015; Niven et al., 2015; Smith, 2004; Wolfson, Granstrom, Pomarico, & Reimanis, 2013). However, oral thermometers pose potential problems in oncology settings and are typically avoided because of the risk for mucosal membrane bleeding during probe placement, pain associated with oral mucositis, and contraindications related to radiation or surgery to the head and neck (Bridges & Thomas, 2009; Gobel & O'Leary, 2007; Mason et al., 2015). Several alternative thermometers are available, including tympanic and temporal artery thermometers. Although a number of studies have compared the accuracy of these alternatives to the oral thermometer, substantial variability exists in the methodologies and patient populations that have been studied, making it difficult to draw firm conclusions (Bonzi, Fiorelli, Solbiati, & Montano, 2016; Bridges & Thomas, 2009; Niven et al., 2015). For example, many studies comparing noninvasive thermometers have been conducted with pediatric patients (Allergaert, Casteels, van Gorp, & Bogaert, 2014; Hebbar, Fortenberry, Rogers, Merritt, & Easley, 2005; Lee et al., 2011; Opersteny et al., 2017; Penning, van der Linden, Tibboel, & Evenhuis, 2011; Reynolds et al., 2014; Teran et al., 2012; Zhen et al., 2015), but anatomical differences in blood vessel position and in the types of thermometers that are compared

(such as axillary and rectal) make it hard to generalize the results to adults (Niven et al., 2015). Among the studies conducted with adults (Bridges & Thomas, 2009; Calonder et al., 2010; Fountain et al., 2008; Frommelt, Ott, & Hays, 2008;), only two investigated patients with fevers (Stelfox et al., 2010; Wolfson et al., 2013), and the only study with neutropenic adult patients with cancer did not include febrile participants (Mason et al., 2015).

In addition to differences in methodology and population, differences also exist in the rigor of statistical analysis that each study has employed. A thermometer is considered to accurately approximate true core temperature if the temperature difference between the test thermometer and an oral thermometer (gold standard) is 0.3°C or less (known as bias), and the standard deviation of this difference is 0.5°C or less (known as precision) (Fountain et al., 2008; Lawson et al., 2007; Wolfson et al., 2013). Many studies use only descriptive statistics to compare thermometers within a specific population, making it difficult to generalize the results (Bridges & Thomas, 2009; Niven et al., 2015).

The purpose of this study was to investigate the accuracy of two alternative, noninvasive thermometers (tympanic and temporal artery) when used to measure the temperatures of adult patients with cancer with and without fevers. Fever was defined as a temperature greater than 38°C (Polovich et al., 2014). Thermometer accuracy was assessed by comparing each thermometer to the gold standard nondisposable oral electronic thermometer and by analyzing the results in terms of bias and precision.

Methods

This study was conducted at Emory University Hospital, a Magnet-designated facility in Atlanta, Georgia, on a 23-bed inpatient oncology unit. Study approval was obtained from the institutional review board prior to data collection.

Design

A method-comparison study design was used to compare two different test thermometers, tympanic and temporal artery, to the gold standard oral thermometer in adult patients with cancer with and without fevers. Each participant served as his or her own control, receiving all three temperature measurements. The primary dependent variable was the difference in temperature between the test thermometers and the oral thermometer.

Instruments

Tympanic temperatures were measured with a Genius® Model 2 according to the manufacturer's directions. The manufacturer specifications include a clinical accuracy of ± 0.1°C for temperatures ranging from 33°C–42°C.

Temporal artery temperatures were measured with a Temporal® Scanner TAT 5000 according to manufacturer's directions. The manufacturer specifications include a clinical accuracy of ± 0.1°C for temperatures ranging from 16°C–43°C.

> **"Inaccuracy may lead to false fever identification and unnecessary clinical interventions."**

Oral electronic temperatures were measured with a SureTemp® Plus Model 690 according to manufacturer's directions. The manufacturer specifications include a clinical accuracy of ± 0.1°C for temperatures ranging from 26.7°C–43.3°C. Oral electronic thermometers (nondisposable) have been shown in prior studies to closely approximate invasive core temperatures and have been used as the clinical reference standard temperature device in clinical studies when invasive temperature devices are contraindicated or not available (Mason et al., 2015; Wolfson et al., 2013).

Sample Selection

The majority of participants were adults diagnosed with multiple myeloma and were admitted to an inpatient unit for bone marrow transplantation (see Table 1). Participants in this study had no medical contraindications or physical impediments (i.e., stomatitis; oral abscess; head trauma; or recent ear, nose, or throat surgery) to obtaining temperature measurements with the three study thermometers. Inclusion criteria were no ingestion of hot or cold liquids, chewing gum, smoking, showering, or exercise within 15 minutes prior to temperature measurement; absence of a hat, head wrap, or head bandage for 15 minutes prior to temperature measurement; no antipyretic or acetaminophen-based medications within the past six hours; and absence of combative or agitated behavior. Patients receiving end-of-life care were excluded from the study.

A minimum sample size of 48 participants was determined with power analysis for paired t test on a group of participants with normal (less than 38°C, n = 24) and elevated temperatures (38°C or greater, n = 24). Power was set at 0.8, effect size at 0.6 (moderate), and alpha level at 0.05 (Faul, Erdfelder, Lang, & Buchner, 2007). A total of 50 critically ill patients were studied (24 febrile patients and 26 afebrile patients). Participants' ages ranged from 20–74 years ($\bar{X}$ = 50, SD = 12.7).

Procedures

Prior to beginning the study, investigators were trained in the proper use of each thermometer, based on the manufacturer's guidelines. Inter-rater reliability was determined by having

each investigator practice temperature measurement until two sequential investigators' temperatures were within 0.1°C for each thermometer. Prior to starting the study, the three thermometers were restricted for study use. The clinical engineering department at the study hospital calibrated the three thermometers according to the manufacturer specifications.

Following informed consent of the study participants, investigators obtained demographic and patient characteristic data from the medical record. Temperatures were sequentially measured with each of the three thermometers. All three measurements were obtained by one of the study investigators within a five-minute period according to a standard procedure. Participants were randomly assigned to one of two groups. Participants in group 1 received measurements with the tympanic, then temporal artery, and then oral thermometers. Group 2 received measurements with the temporal artery, then tympanic, and then oral thermometers. The oral thermometer was always used last to ensure that the investigators did not know the patient's reference temperature (oral) prior to obtaining the other two measurements. This eliminated any possibility that investigators could unconsciously bias data collection.

Statistical Analysis

The data were reviewed for completeness, missing data, and outliers. Data summaries were performed using descriptive statistics. Differences and limits of agreement between the test thermometers (tympanic and temporal artery) and the reference (oral) thermometer were calculated and graphed according to the Bland–Altman method (Bland & Altman, 1986, 1995). Repeated-measures analysis of variance and Sidak multiple pairwise error rate adjustment test was used to determine if significant differences existed between the two test temperature devices (tympanic and temporal artery) and the oral reference thermometer. Stepwise multivariable regression analysis was performed to determine if any significant differences between the test and reference thermometers were related to patients' body temperature, rather than other variables, such as demographics or diagnosis. The level of significance for all statistical tests was established at $p < 0.05$.

Results

No statistically significant differences existed in demographic or diagnosis information between group 1 (tympanic, temporal artery, and oral) and group 2 (temporal artery, tympanic, and oral), meaning that the order of temperature measurement did not affect the results. In addition, no significant difference was noted in the temperatures obtained with the same thermometer between group 1 and group 2 ($F[2,96] = 0.747$; $p = 0.476$). Temperatures measured with the tympanic thermometer ranged from 35.3°C–40.2°C ($\bar{X}$ = 37.6°C, SD = 1.13°C). Measurements were slightly higher for the temporal artery thermometer, ranging from 36.4°C–41.6°C ($\bar{X}$ = 38.3°C, SD = 1.28°C). Oral thermometer measures were lowest, ranging from 36.3°C–39.5°C ($\bar{X}$ = 37.5°C, SD = 0.82°C) (see Table 2).

TABLE 1.
SAMPLE CHARACTERISTICS BY GROUP

	GROUP 1 (N = 23)	GROUP 2 (N = 27)	
CHARACTERISTIC	$\bar{X}$	$\bar{X}$	**p**
Age (years)	56.4	61.3	0.17
CHARACTERISTIC	**n**	**n**	**p**
Gender			0.665
Male	15	16	
Female	8	11	
Ethnicity			0.052
Caucasian	9	18	
African American	12	9	
Latino	2	–	
Cancer type			0.945
Breast	1	2	
Lung	2	3	
Gastrointestinal	1	2	
Germ cell	1	–	
Blood	13	15	
Skin	1	–	
Other	4	5	
Reason for hospitalization			0.219
Chemotherapy	6	2	
Bone marrow transplantation	7	10	
Intractable pain	2	2	
Respiratory distress	1	3	
Adverse effects of prior chemotherapy	–	2	
Intractable nausea, vomiting, diarrhea	–	2	
Other	7	6	

Note. The standard deviation for age was 12.6 years in group 1 and 12.7 years in group 2.
Note. Group 1 consisted of tympanic, temporal artery, and oral thermometers, and group 2 consisted of temporal artery, tympanic, and oral thermometers.

However, significant differences in temperatures were noted when comparing the three thermometers to one another ($F[2,96] = 44.672$; $p < 0.001$), with the temporal artery thermometer having significantly higher temperatures than the tympanic thermometer ($p < 0.001$) and oral thermometer ($p < 0.001$). When compared to the oral thermometer, the tympanic thermometer was not significantly different ($p = 0.381$), with temperature differences ranging from –1.2°C below the oral standard to 1.3°C above, with a mean difference (bias) of 0.126 and standard deviation of these differences (precision) of 0.616. However, the significant differences between the oral thermometer and the temporal artery thermometer ($p < 0.001$) had temperature differences ranging from –0.4°C below the oral standard to 2.5°C above, with a mean difference (bias) of 0.796 and a standard deviation of these differences (precision) of 0.718.

The Bland–Altman plots in Figures 1 and 2 show the differences between the test thermometers (tympanic or temporal artery) and oral thermometer, plotted against the average temperature of the two thermometers compared (i.e., tympanic temperature plus oral temperature divided by 2). In these plots, bias of the test thermometer (tympanic or temporal artery) compared to the oral thermometer is shown, including the 95% confidence intervals (CIs) illustrating the limits of agreement between the test thermometer and oral standard. For the tympanic thermometer, 3 of 50 differences (6%) between the tympanic temperatures and the oral standard were outside (below) these 95% CI limits. For the temporal artery thermometer, only 1 (2%) of the differences fell outside the 95% CI limits for the bias.

As patients' temperatures increased, so did the difference between the temporal artery and oral thermometers (see Figure 3). That is, the greater the patient's temperature, the lower the agreement between devices. To further investigate this result, multivariable regression using stepwise variable selection methods was performed to test whether significant associations existed between the patient's temperature (as measured using the oral standard) and other variables, such as patient's age, gender, ethnicity (Caucasian versus other), diagnosis (blood cancer versus other), and group (order of testing). There was a positive association between increasing oral temperature and temperatures measured with both test thermometers. For the tympanic thermometer, this association was not significantly associated with any specific variable. However, for the temporal artery thermometer, the association was significant ($p = 0.011$), with greater positive differences among Caucasian patients ($p = 0.049$). Taken together, patients' (oral) temperature and ethnicity explained 18.9% ($r^2 = 0.189$) of the variability in the differences between the temporal artery and the oral standard thermometers. Additional studies are needed to determine if this finding has any clinical significance.

TABLE 2.
TEMPERATURE RANGES MEASURED WITH EACH THERMOMETER TYPE

DEVICE	$\bar{X}$	SD	RANGE
Tympanic (°C)[a]	37.6	1.13	35.3, 40.2
Temporal artery (°C)[b]	38.3	1.28	36.4, 41.6
Oral electronic (°C)	37.5	0.82	36.3, 39.5
COMPARISON	$\bar{X}$	**SD**	**RANGE**
Δ Tympanic–oral (°C)	0.126	0.616	–1.2, 1.3
Δ Temporal artery–oral (°C)	0.796	0.718	–0.4, 2.5

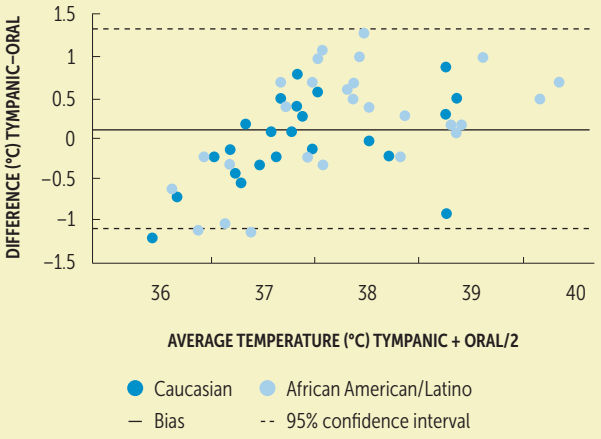
[a] Bias = 0.126, precision = 0.616
[b] Bias = 0.796, precision = 0.718
Δ—delta/change
Note. Bias values 0.3°C and lower and precision values 0.5°C and lower are within the recommended range for clinically acceptable equivalency with the electronic oral thermometer.

Discussion

The test thermometers (tympanic and temporal artery) were not as accurate as the oral thermometer when the results were analyzed in terms of bias and precision. Although temperatures obtained with the tympanic thermometer were not significantly different from the oral thermometer using traditional statistics, more detailed analysis indicated that this difference (precision = 0.6) was outside the acceptable level for thermometer accuracy (Forbes et al., 2009; Fountain et al., 2008). The tympanic thermometer may have given readings that were not significantly different from the oral thermometer in the context of this study because the investigators were specifically trained and used the correct technique with each thermometer every time. However, a number of previous studies and meta-analyses have cautioned against using tympanic thermometers because of the possibility for wide variability in technique and, therefore, user error in real-world settings (Allergaert et al., 2014; Bridges & Thomas 2009; Fountain et al., 2008; Frommelt et al., 2008; Niven et al., 2015).

Temperatures obtained with the temporal artery thermometer were also less accurate than predicted, with temperatures differing significantly from the oral thermometer, and both precision and bias falling outside the acceptable range for accuracy (bias = 0.796, precision = 0.7). Several previous studies with afebrile patients have found no significant difference between temporal artery and oral thermometers, concluding that they are an appropriate alternative when oral thermometers are contraindicated (Barringer et al., 2011; Lee et al., 2011; Mason et al., 2015; Opersteny et al., 2017; Reynolds et al., 2014; Teran et al., 2012). However, unlike in the current study, these investigations focused primarily on pediatric populations or did not include febrile participants. The difference between temperatures measured with the temporal artery and oral thermometers significantly

FIGURE 1.
TYMPANIC VERSUS ORAL THERMOMETERS



Note. The upper 95% confidence interval is 1.33 and the lower 95% confidence interval is –1.08. Bias is 0.126.

increased as the patients' oral temperature increased. In other words, the temporal artery thermometer became less accurate as patients became more febrile. This may explain differences in the results of the current study in comparison to previous studies with afebrile participants, and provides support for previous studies that have included febrile patients and found unacceptable differences among the temporal artery thermometer and either the oral or invasively measured true core temperatures (Fountain et al., 2008; Hebbar et al., 2005; Kimberger et al., 2007; Stelfox et al., 2010; Wolfson et al., 2013). In a meta-analysis of 75 studies comparing noninvasive thermometers to central thermometers that measure core temperature, Niven et al. (2015) concluded that tympanic and temporal artery thermometers do not have a clinically acceptable level of agreement when compared to core temperature and have poor sensitivity for detecting low-grade fever. In addition, Niven et al. (2015) suggest that oral thermometry may be the best noninvasive alternative when core temperatures cannot be measured.

The results of this study indicate that, although temporal artery thermometers have been shown to be an accurate substitute for oral thermometers in normothermic patients, they may not be as accurate as predicted with febrile patients. This inaccuracy may lead to false fever identification and unnecessary clinical interventions, such as antimicrobial therapy, blood cultures, and x-rays. In the context of oncology, oral thermometry may be the best method of temperature measurement for patients who can tolerate correct placement of the oral probe. However, the results of this study may have wider implications for temperature measurement in other settings, such as outpatient care, nononcology populations, and home thermometry. This study's results suggest that oral electronic thermometers provide the most accurate approximation of true core temperature and should, therefore, be the preferred method of temperature measurement when possible.

Limitations

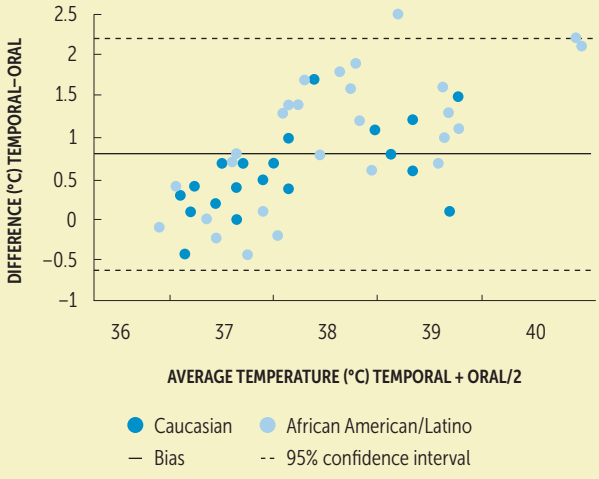
The results of this study have some imitations. First, data collection was from a convenience sample of patients admitted to an inpatient oncology unit. Patients could only be enrolled in the study when one of the study investigators was present on the unit; therefore, not every patient who met inclusion criteria was approached to participate. All potential participants were approached if a study investigator was present (and only 1 of the 51 patients approached declined). Although the study included participants of both genders, multiple ethnicities, and a variety of cancer diagnoses, care should be taken when generalizing the results to oncology populations not represented in the dataset.

Second, the bias and precision values of the tympanic and temporal artery thermometers may not mirror actual clinical practice because the temperatures measured in the current study were obtained by the study investigators, who represent a limited number of specifically trained individuals. In clinical practice, many different clinicians obtain temperatures and optimal technique may not always be followed.

Implications for Practice

The results of this study suggest several implications for change in clinical practice. The accuracy of the temporal artery thermometer decreased with increasing oral temperature. The use of

FIGURE 2.
TEMPORAL ARTERY VERSUS ORAL THERMOMETERS



Note. The upper 95% confidence interval is 2.2 and the lower 95% confidence interval is –0.61. Bias is 0.796.

temporal artery thermometers may lead to false identification of fevers and, subsequently, unnecessary clinical interventions such as antimicrobial therapy, blood cultures, and x-rays.

Conclusion

Accurate temperature measurement in patients with cancer is critical. The results of the current study suggest that oral thermometers should be used whenever possible within a wide range of settings and populations and that care should be taken when interpreting temperatures from alternative thermometers in febrile patients. The results also highlight that thermometer technology has room for improvement (Niven et al., 2015), leaving few available alternatives to oral thermometry for oncology (and other special populations) (Bonzi et al., 2016). Modifications to the oral probe or innovations to decrease the possibility of user error with tympanic thermometers may greatly improve the accuracy of temperature measurement in the future.

IMPLICATIONS FOR PRACTICE

- Educate fellow nurses and healthcare providers that neither temporal artery nor tympanic thermometers accurately approximated true core body temperature.
- Take caution when interpreting temperatures taken with alternative thermometers for febrile patients; inaccuracy was most pronounced for this population.
- Use oral electronic thermometers whenever possible; they provide the most accurate approximation of true core body temperature.

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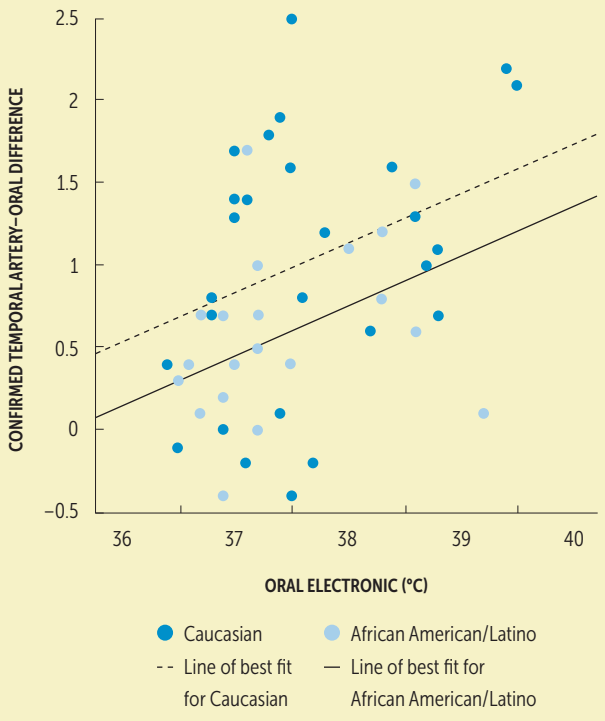
FIGURE 3.
TEMPERATURE DIFFERENCE BETWEEN TEMPORAL ARTERY AND ORAL THERMOMETERS



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