IS TEMPORAL ARTERY THERMOMETRY A USEFUL INDICATOR OF CORE BODY TEMPERATURE IN PATIENTS RECEIVING GENERAL ANESTHESIA?

by

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IS TEMPORAL ARTERY THERMOMETRY A USEFUL INDICATOR OF CORE BODY TEMPERATURE IN PATIENTS RECEIVING GENERAL ANESTHESIA?

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Anesthetic medications and the cold operating room environment are among the factors that increase the risk of decreased core body temperature in surgical patients, which can put a patient at risk for untoward physiologic responses. Therefore, peripheral thermometry methods, like the temporal artery thermometer, have been questioned as an accurate indicator of core body temperature. To determine the usefulness of the temporal artery thermometer in patients receiving general anesthesia, three specific aims were set. First, the study compared the accuracy of temporal artery temperature (Tat) to esophageal temperature (Tes) in estimating core body temperature in the operating room. Second, Tat's accuracy was compared with oral temperature (Tor) in the post anesthesia care unit (PACU). Lastly, this study determined factors that were associated with the level of agreement between Tes and Tat from the beginning of anesthesia administration (induction time point) to the time the patient is awakened from anesthesia (emergence time point).

A prospective repeated measures design was used at three time points (induction, emergence, and in the post-anesthesia care unit (PACU). Temperatures were collected in 54 surgical patients requiring general anesthesia and Tat was compared to Tes intraoperatively and Tor postoperatively. Data analysis included descriptive statistics, t-test comparison of temperatures, and generation of Bland Altman plots to examine the agreement between thermometry methods. Multiple linear regression was also used to identify factors associated with the agreement between methods.

Results showed that Tes and Tor were all found to be statistically significant for being lower compared to Tat at all three time points. The temporal artery thermometer results produced overestimation of core body temperature paralleled with a poor ability to detect hypothermia. Additionally, the use of muscle relaxants and the location of the surgical site incision (torso compared to neck) were associated with the difference between Tat and Tes from induction to emergence. Therefore, although Tat is more convenient than other thermometry methods, the temporal artery thermometer should be substituted with better indicators of core body temperature to avoid risks of perioperative hypothermia, which is defined as a body temperature less than 36˚C.

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1.0 INTRODUCTION

Monitoring core body temperature of patients in the perioperative environment is required for early and accurate detection of hypothermia and malignant hyperthermia, a rare complication of general anesthetic administration.

In MH susceptible patients, this dangerous hypermetabolic reaction caused by the administration of common volatile anesthetics such as desflurane, sevoflurane, and isoflurane, and, the depolarizing muscle relaxant, succinylcholine can be fatal if not properly recognized and treated.[10,11] MH is an autosomal dominant myopathy causing an adverse metabolic or muscular reaction to anesthesia (AMRA) presenting with a rise in intracellular calcium, rigidity, increased core body temperature, increased carbon dioxide production, and increased oxygen consumption, largely affecting the skeletal muscles.[10,11] As the muscle cells rigorously contract due to release of calcium, a subsequent increase in potassium and creatinine kinase, acidosis, and myoglobinuria, leads to lethal cardiac arrhythmias and dysfunction.[10] The risk has been reported to vary between less than one of 50,000 to 250,000 anesthetic medication exposures. This risk can increase to between one in 20,000 to 30,000 individuals in clusters of susceptible people with the at-risk gene, due to the sharing of the MH genetic trait through generations.[10] However, this does not explain for the individuals who may experience MH even after 4-5 uncomplicated administrations of anesthetic medications.[10] The high temperatures from this complication cause apoptosis that leads to irreversible tissue damage, making the mortality and recovery rate very grim for the MH-susceptible. [11] For this reason, the American Society of Anesthesiologists (ASA) recommends continuous and reliable core temperature monitoring to allow providers to intervene before the patient becomes critical.[11]

When looking at the preventative measures to avoid the incidence of MH, researchers looked at 84 of 189 cases of pediatric AMRA, which included seven cardiac arrests, no successful resuscitations, and eight deaths.[11] Considering factors such as demographic data, family history, previous anesthesia reactions, time of when the anesthetic reaction occurred, and clinical MH signs, the study looked at the relationship of a patient's risk of dying from MH and what kind of temperature monitoring (no probe, skin temperature probe, and core body temperature probe) was used during the operation.[11] The results of the study showed a 30% mortality in patients with no probe, 21% mortality in patients with a skin temperature probe, and a 2% mortality in patients with a core body temperature probe.[11] All deaths in the study were patients with a temperature of 38.9°C or higher and most patients with the higher temperatures did not have a temperature probe or used only a skin temperature probe.[11] Nine patients reached temperature exceeding 41°C and out of those 9, only 3 survived.[11] Two of those 9 patients were monitored using a core body temperature probe and both survived, proving the importance of proper temperature monitoring.[11] Researchers noted that 10% of the MH cases resulted in death, which is an increase from a cohort collected six years ago.[11] This was an alarming finding because of the well-known use of the MH antidote dantrolene and the thorough knowledge scope of anesthesia providers regarding AMRA.[11] Researchers attribute this increased mortality to the failure of adopting a common temperature monitoring practice, since only one patient with core body temperature monitoring had died in the study compared to 21% with only skin temperature monitoring dying.[11] When comparing core body temperature monitoring to no temperature monitoring, the risk of death doubled; and when compared to skin temperature monitoring, the mortality risk of patients is increased by at least 50%.[11] Therefore, although the first signs of MH include muscle rigidity, increased heart rate, and elevated end-tidal CO_2 readings, proper temperature monitoring is still a vital assessment in preventing serious life-threatening complications of MH.[8]

Along with the serious health consequences associated with MH due to poor temperature monitoring, perioperative hypothermia is also a major concern in surgical patients receiving general anesthesia. Depending on various risk factors, including age, nutritional status, comorbidities, and type of surgery, a patient's risk for hypothermia is between 26-90%.[1] This high incidence of hypothermia in surgical patients receiving general anesthetics is clinically important because of the significant complications associated with body temperatures falling below 36˚C. Hypothermia in the surgical setting includes augmented risks of blood loss and need for allogeneic transfusions, life-threatening cardiac complications, and surgical site infections.[2-4] Initial vasoconstriction from a reduced body temperature can cause an increase in afterload and increased cardiac work. There is also a risk for cardiac arrhythmias that can deteriorate to ventricular fibrillation or asystole.[5]

Additionally, the thermoregulatory vasoconstriction that is triggered by hypothermia causes a decrease in the partial pressure of oxygen in subcutaneous tissues, which impairs oxidative neutrophil killing.[6] With the decreased microbial defense, immune functions are also compromised and scar formation is decreased proportional to the wound's oxygen tension.[4,6] Vasoconstriction therefore slows the patient's healing and recovery due to the diminished ability of the body to oxygenate the surgical site.[7] In one double-blind randomized trial of 80 surgical patients aged 18 to 80 years who underwent elective colorectal resection for cancer or inflammatory bowel disease, occurrence of mild perioperative hypothermia (about 2˚C below normal temperature) caused a threefold increase in the risk of surgical-wound infection and prolonged a patient's hospital stay by 20%.[3,6] A sense of feeling cold post-operatively has also been shown to alter awareness, cause physiological stress, and lengthen the amount of time it takes to wake the patient up from anesthesia.[8] The elongated time for emergence can also be due to slowed metabolism caused by hypothermia, which increases plasma concentrations of medications and makes it more difficult for the patient to eliminate anesthetic agents efficiently.[7,8]

Perioperative hypothermia can also cause respiratory and metabolic abnormalities in severely hypothermic patients; in the most serious cases it is associated with an increased risk for patient death.[5] A major concern in patients with decreased core body temperatures are coagulopathies and increased bleeding, which can directly affect surgical outcomes. Decreased core body temperature is associated with cold-induced inhibition of platelet function and impaired activity of the enzymes in the coagulation cascade.[8] Studies have shown that cold temperatures decrease the release of thromboxane A_2, which impacts platelet function, and lengthen prothrombin and partial thromboplastin times, which slows enzymatic reactions.[4] Even mild hypothermic states can begin to impair coagulation. A systematic review and meta-analysis of the effects of hypothermia on coagulation found an estimated 16% increase in blood loss (95% CI = 4-26%).[9] It also increased a patient's need for a transfusion by 22% (95% CI = 3-27%).[9] In conclusion, because of these numerous reasons, proper temperature monitoring in the surgical patient population is vital in maintaining safety, promoting a full recovery, and avoiding medical complications.

Temperature, one of the four main vital signs is inarguably crucial to check considering the potential risks in respect to perioperative temperature alterations. The operating room (OR) temperature is maintained below 23˚C; however, most surgical personnel find this temperature uncomfortably warm and very commonly surgeons prefer a temperature as low as below 20˚C.[2] For a patient going into surgery, a thin gown, the cooler room temperature, and the effect of anesthetic drugs increase risk for hypothermia.

The operating room environment contributes to heat transfer processes, which include radiation, conduction, convection, and evaporation in the surgical patient.[8] In particular, radiation (heat loss from the body to the environment) is a major source of heat loss in surgical patients and accounting for about 60% of the total heat loss during surgery.[4,8] Another heat transfer process seen in surgical patient is conduction, which occurs when patients are placed on a cold operating room table and the heat is lost.[5] Convection is another concern in patients in the OR due to the frequent air exchanges that occur to maintain an aseptic environment.[5] If patients are not well covered when traveling from the preoperative holding area to the OR they will lose heat by convective heat loss as they are transported. Evaporative heat loss can also occur due to the prep solution used to prepare the surgical site and from an open abdominal or thoracic procedure.[5]

Along with the effect of these normal heat transfer processes, anesthesia can also increase the patient's risk for hypothermia since it impairs thermoregulatory mechanisms.[2,4] Anesthetic agents inhibit cold-induced vasoconstriction and this vasodilating action brings blood closer to the skin's surface, promoting heat loss to the environment by redistributing heat from the core to the periphery.[2-4] General anesthetics can also decrease shivering thresholds by 2-3˚C, preventing typical body response to maintain body temperature in cold environments.[4,12,13]

There is a challenge that healthcare providers face when deciding optimal temperature monitoring in the perioperative setting. It is important to have an accurate temperature reported, but practical factors should be considered as well. When it comes to measuring temperature, there are two common approaches: central and peripheral thermometry. Central thermometry measures core body temperature through the blood supplying organs like the brain, abdominal, and thoracic cavities, representing the temperature of highly perfused tissues and thus is the best indicator for body temperature.[3,4] This approach includes invasive thermometry tools such as pulmonary artery catheters, brain tissue oxygen monitoring systems, or temperature probes into the esophagus or the urinary bladder.[4,14] Peripheral thermometry, measures body temperature in less invasive places such as the ear or the skin over the forehead, rectum, axilla and oral cavity, yet these sites are not as accurate as central indicators of temperature and are typically 2-4˚C less than core temperatures.[3,4,14] The multitude of methods to measure temperature vary greatly in efficiency and accuracy.

The use of the temporal artery thermometer has been questioned by several studies. Although it is noninvasive and efficient, it is questionable whether it is accurate and reliable when monitoring a patient's temperature.[14-16] The temporal artery is located about a millimeter below the skin's surface at the forehead and stems from the carotid artery, which is connected to the heart from the aorta that provides constant blood supply.[17] This type of thermometer uses a probe to scan the naturally emitted heat from the skin surface above the temporal artery with an infrared technology and takes the highest temperature of the arterial blood supply it detects, while a second system measures the ambient temperature of the area to obtain the "arterial heat balance" (AHB).[17] These two measurements are then used in a patented algorithm to predict the patient's core body temperature.[17] However, many factors that can cool the skin naturally and the effects of environmental temperature may decrease its accuracy.

Due to the questionable and debatable accuracy of the temporal artery thermometer, we set out to determine if temporal artery thermometry is an appropriate measurement tool in surgical patients receiving general anesthesia. The esophageal thermometer was used as the gold standard in this study because it measures core temperatures near the heart.[4,13] In the PACU, where core temperature monitoring is not recommended, oral thermometry is commonly used and is considered a good indicator of body temperature as it correlates well with core temperature measures.[18] Comparing temporal to oral thermometer measurements in the PACU would help in determining whether temporal artery thermometry is an accurate measurement of a patient's temperature during the post-operative period once outside the operating room. Further, we wished to look at which personal and environmental factors, including as age, gender, race, surgical site, length of surgery, operating room temperature, and use of various anesthetizing medications may affect the difference observed between Tat and Tes measurements from induction to emergence.

2.0 PURPOSE OF THE STUDY

The purpose of this study is to compare an indicator of peripheral temperature measure [temporal artery thermometer (Tat)] with standard measures of temperature [esophageal thermometer (Tes) and oral thermometer (Tor)] during the perioperative period. The specific aims of this study were to 1) determine the agreement between Tat and Tes at the initiation of general anesthesia (i.e. induction) and during emergence from general anesthesia in the OR; 2) determine the agreement between Tat and Tor in the PACU and 3) explore the factors that may be associated with the difference between Tat and Tes measurements from induction and emergence.

2.1 MATERIALS AND METHODS

The study took place at the Presbyterian Hospital of the University of Pittsburgh Medical Center (UPMC). This study was approved by the University of Pittsburgh IRB. Informed consent was obtained from all participants prior to initiation of any study procedures.

2.1.1 Study Design and Sample Selection

A prospective repeated measures design was used to collect data using a convenience sample of 54 subjects at least 18 years of age who were undergoing general anesthesia. Participants were included if they were receiving general anesthesia for a surgical procedure [neck (20.4%), spinal (20.4%), torso (38.9%), extremities (14.8%), unknown (5.6%)] with planned esophageal temperature monitoring. Eligible participants were excluded if there was inability to access the patient's forehead for the use of the Tat due to the nature of surgery. All participants had Tat measured at three time points: induction, emergence, and within 15 minutes of admission to the PACU. At induction and emergence, Tes was collected in addition to Tat. In the PACU, Tor was collected with Tat.

2.1.2 Standard of Care

Once the surgical patient was brought into the OR for surgery, the patient was attached to the monitors, started on medications and fluids, induced with general anesthetics, and intubated with an esophageal probe. Medications administered include induction agents such propofol, opioids including fentanyl, and muscle relaxants including succinylcholine and rocuronium. Vasoactive medications and intravenous fluids including crystalloids and colloids were administered as needed. The surgical site was prepped using betadine or chlorhexidine.

After anesthesia was induced, the patient was draped, and the sterile field was established, convective warmers set at 43˚C were utilized on all participants. After, induction Tat and Tes measurements were obtained. When the procedure was starting to close, the anesthesia provider began to wean the patient from anesthetizing medications and recorded the patient's Tat and Tes measurements at this emergence time point. Once extubated and stabilized, the patient was moved into the PACU and Tor and Tat were both collected within 15 minutes of admission.

2.1.3 Potential Covariates

We collected and considered several variables in this study, including age, gender, race, body surface area (BSA), ASA physical status classification, surgical site (neck, torso, spine, extremity), length of surgery, operating room temperature, use of intravenous (IV) fluid, fentanyl, muscle relaxants, vasopressors, midazolam, and propofol.

2.1.4 Measures

Tat was measured using an Exergen Temporal Scanner (Watertown MA). Tat was collected by certified registered nurse anesthetists (CRNAs) who were trained to use the temporal scanner beforehand following the manufacturer's recommendations. Tat was recorded at all 3 time points on study data collection sheets. The accuracy of the Exergen Temporal Scanner is reported to be ± 0.1°C for temperatures between 16°C to 43°C.[19]

Tes was measured using the Level 1 Acoustascope Esophageal Stethoscope Model ES400-18 (Smiths Medical ASD, Inc., Rockland MA). The accuracy of the Yellow Springs Instrument thermistor is ± 0.05 to ± 0.2°C.

Tor was measured using the Becton Dickinson Digital Thermometer in the PACU as per protocol. Tor was recorded in the PACU on study data collection sheets. The accuracy of the Becton Dickinson Digital Thermometer is ± 0.1ºC.

Study personnel collected demographic information [gender, race, age, weight, height, body mass index (BMI), and BSA] from medical records upon study enrollment. Medication and dosages, ASA perioperative risk, surgical site of operation, length of surgery, and temperature of OR were also extracted from the operative time period and documented on data collection sheets.

2.1.5 Statistical Analyses

STATA version 14 (StataCorp. 2015. *Stata Statistical Software: Release 14*. College Station, TX: StataCorp LP.) was used for all analyses. Descriptive statistics were used to summarize the characteristics of the sample and temperature values at each time point. Paired t-test analyses were used to investigate the differences between the means of the thermometry methods within each patient at each time period, including the differences between the Tat and Tes during the operation (at induction and emergence) and between Tat and Tor post-operatively in the PACU. Bland-Altman plots were generated to examine the variability in temperature agreement over the observed temperature range between 1) Tat and Tes and 2) Tat and Tor at each of the three time periods. Bland-Altman plots display the differences in values between the thermometry methods to determine the accuracy of the Tat compared to a more clinically relevant method (i.e., oral or esophageal), where the average between the measurements is plotted against the difference between the temperature measurements along with the lower and upper 95% confidence limits for the mean differences.

To explore whether any factors were associated with the level of agreement between the Tat and Tes measurements, simple linear regression was first performed to obtain unadjusted estimated regression coefficients. Furthermore, for those factors where regression coefficients are significantly different than zero, one-way analysis of variance (ANOVA), two sample t-test, or correlational analyses, whichever was appropriate given the distribution of the variables involved in the analysis, was used to understand the association between the variables. Lastly, multiple linear regression was applied to obtain adjusted estimated regression coefficients.

3.0 RESULTS

The sample with complete temperature data included 54 patients with an average age of 50.2 years (SD = 15.9). The sample was predominantly Caucasian (n=45), and half male (n=27). Patients were in the OR for on average 116.1 minutes (SD = 78.4). Further description of the sample is reported in Tables 1 and 2.

Table 1. Characteristics of Sample

Characteristics	
Age (y)	
Mean (Standard Deviation)	50.2 (15.93)
(Min, Max)	(17, 84)
Gender, n (%)	
Male	27 (50.0)
Female	26 (48.1)
Unknown	1 (1.9)
Race/Ethnicity, n (%)	
Caucasian	45 (83.3)
African American	5 (9.3)
Other	4 (7.4)
Body Surface Area (m^2)	
Mean (Standard Deviation)	1.99 (0.31)
(Min, Max)	(1.15, 2.72)
ASA, n (%)	
1	5 (9.3)
2	20 (37.0)
3	28 (51.9)
4	1 (1.9)
Surgical Site, n (%)	
Neck	11 (20.4)
Spinal	11 (20.4)
Torso	21 (38.9)
Extremities	8 (14.8)
Unknown	3 (5.6)
Length of Surgery (min)	
Mean (Standard Deviation)	116.1 (78.4)
(Min, Max)	(9, 381)

Operating Room Temperature (℃)	
Mean (Standard Deviation)	19.3 (1.63)
(Min, Max)	(14.4, 21.7)

Table 2. Anesthesia Factors

Anesthesia Factors	Induction	Emergence	PACU
Intravenous Fluid (mL)			
Mean (Standard Deviation)	153.2 (223.3)	1257.5 (900.8)	1344.9 (809.7)
(Min, Max)	(0, 1,000)	(0, 4,000)	(200, 4,000)
Fentanyl (µg)			
Mean (Standard Deviation)	125.9 (63.5)	230.2 (121.8)	238.0 (126.2)
(Min, Max)	(0, 250)	(0, 750)	(0, 750)
Use of Muscle Relaxant, n (%)			
Yes	46 (85.2)	42 (79.3)	40 (76.9)
No	8 (14.8)	11 (20.8)	12 (23.1)
Use of Vasoactive Agent, n (%)			
Yes	11 (20.4)	37 (69.8)	
No	8 (14.8)	16 (30.2)	
Midazolam (mg)			
Mean (Standard Deviation)			1.96 (0.59)
(Min, Max)			(0, 4)
Propofol (mg)			
Mean (Standard Deviation)			261.7 (311.0)
(Min, Max)			(0, 1595)

As reported in Table 3, there were significant differences between the two temperature measurements. At induction, Tat was statistically significantly greater than Tes with a mean difference of -0.67℃ (standard deviation (SD): 0.59℃, 95%CI: -0.83℃ to -0.51℃, $p < 0.0001$). At emergence, Tat also exceeded Tes on average with a mean difference of -0.66℃ (SD: 0.97℃, 95%CI: -0.92℃ to -0.39℃, $p < 0.0001$). In the PACU, the mean difference of -0.41℃ (SD: 0.57℃, 95%CI: -0.57℃ to -0.26℃, $p < 0.0001$) was also statistically significant (Table 3). This is also evident in the box plot (Figure 1), which shows the distribution and differences of the temperature measurement between each thermometry method at each time point.

Table 3. T-Test Results

	Esophageal/Oral (Standard Deviation) (Min, Max)	Temporal artery (Standard Deviation) (Min, Max)	Mean of difference (Standard Deviation) (95% CI)	t value (p value)
Induction	36.05 (0.62) (34.7, 37.5)	36.72 (0.33) (35.9, 37.7)	-0.67 (0.59) (-0.83, -0.51)	t=8.33 (p< 0.0001)
w/o 2 outliers			-0.67 (0.60) (-0.83, -0.50)	t=8.01 (p< 0.0001)
Emergence	36.53 (0.67) (35.1, 37.7)	37.2 (0.90) (35.8, 40.3)	-0.66 (0.97) (-0.93, -0.39)	t=4.90 (p< 0.0001)
w/o 2 outliers			-0.55 (0.79) (-0.77, -0.32)	t=4.86 (p< 0.0001)
PACU	36.34 (0.67) (34.6, 37.6)	36.75 (0.55) (35.4, 38.0)	-0.41 (0.57) (-0.57, -0.26)	t=5.33 (p< 0.0001)

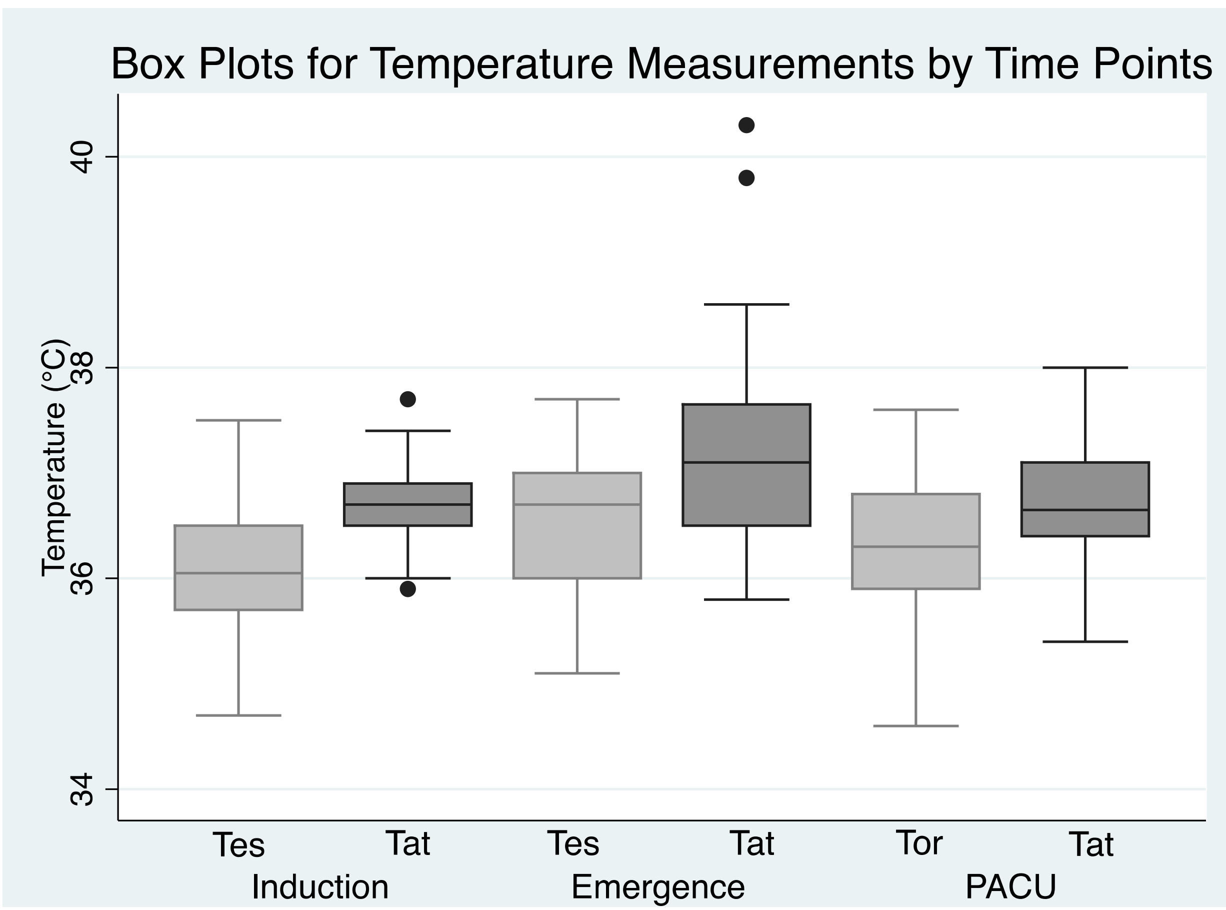

Figure 1. Box Plots for Thermometry Measures at Induction, Emergence, and PACU

The Bland-Altman plot at induction shows a mean difference of -0.67℃ with the 95% confidence interval between -1.83℃ and 0.49℃ for Tat and Tes (Figure 2). When looking at the results in the Bland-Altman plot at induction, it shows that the difference between Tat and Tes is greater when the patient is colder.

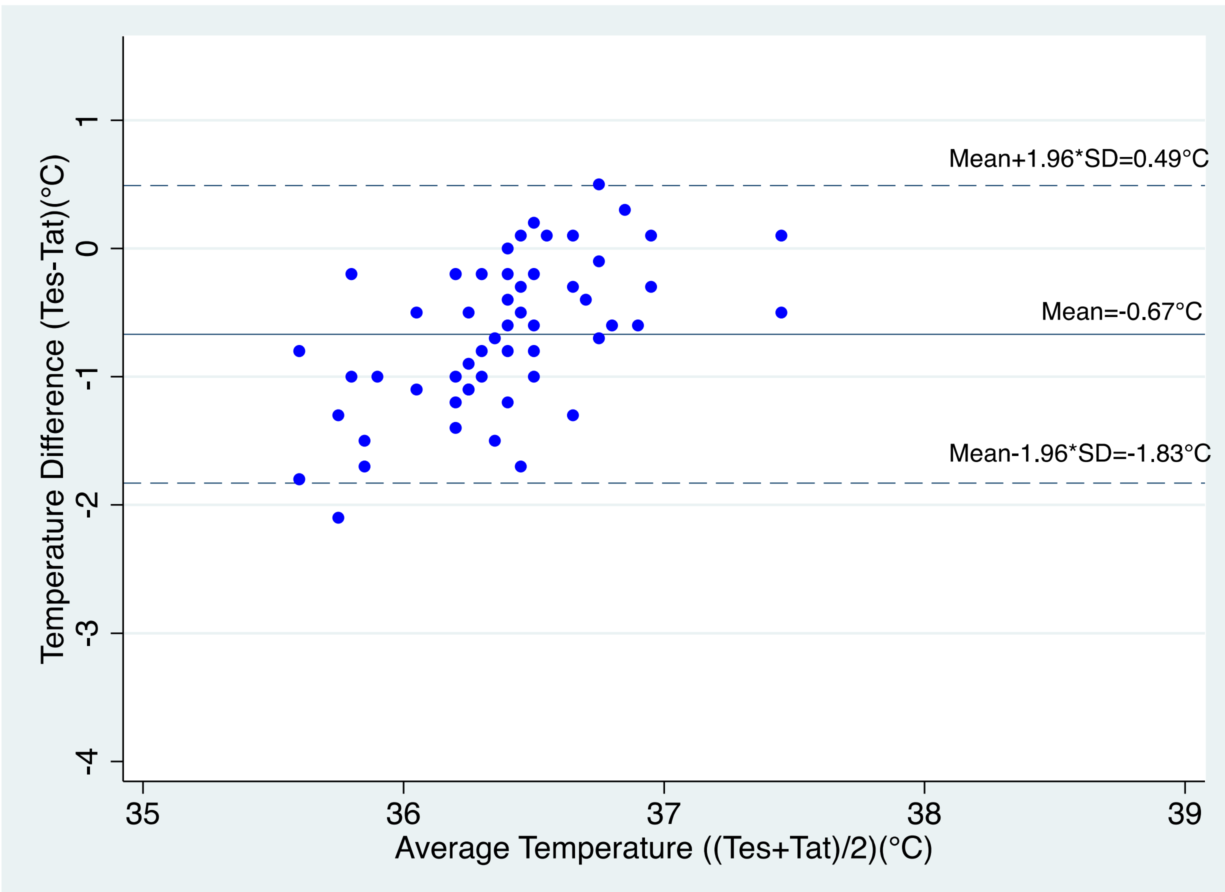

Figure 2. Bland-Altman Plot for Induction

The Bland-Altman plot for temperatures assessed at emergence shows a mean difference of -0.66℃ with the 95% confidence interval between -2.55℃ to 1.24℃ between Tat and Tes (Figure 3). This plot is much more random scatter compared to the induction plot but displays two outliers to the lower right of the graph. In Figure 4, the induction and emergence plots are combined into one graph to depict the visual comparison between the data points at both time periods. The final Bland-Altman plot at recovery in the PACU shows the mean difference between

Tat and Tor is -0.42℃ with the 95% confidence interval between -1.54℃ and 0.71℃ (Figure 5). As for the temperatures assessed at emergence, this Bland-Altman plot looks more random, similar to the Bland-Altman plot at emergence, in that it is difficult to see a systematic pattern between the mean difference average of Tat and Tor values. However, this time point is different from induction and emergence since it is comparing the temporal artery thermometer to an oral thermometer, which is not a core measurement of temperature as an esophageal thermometer probe.

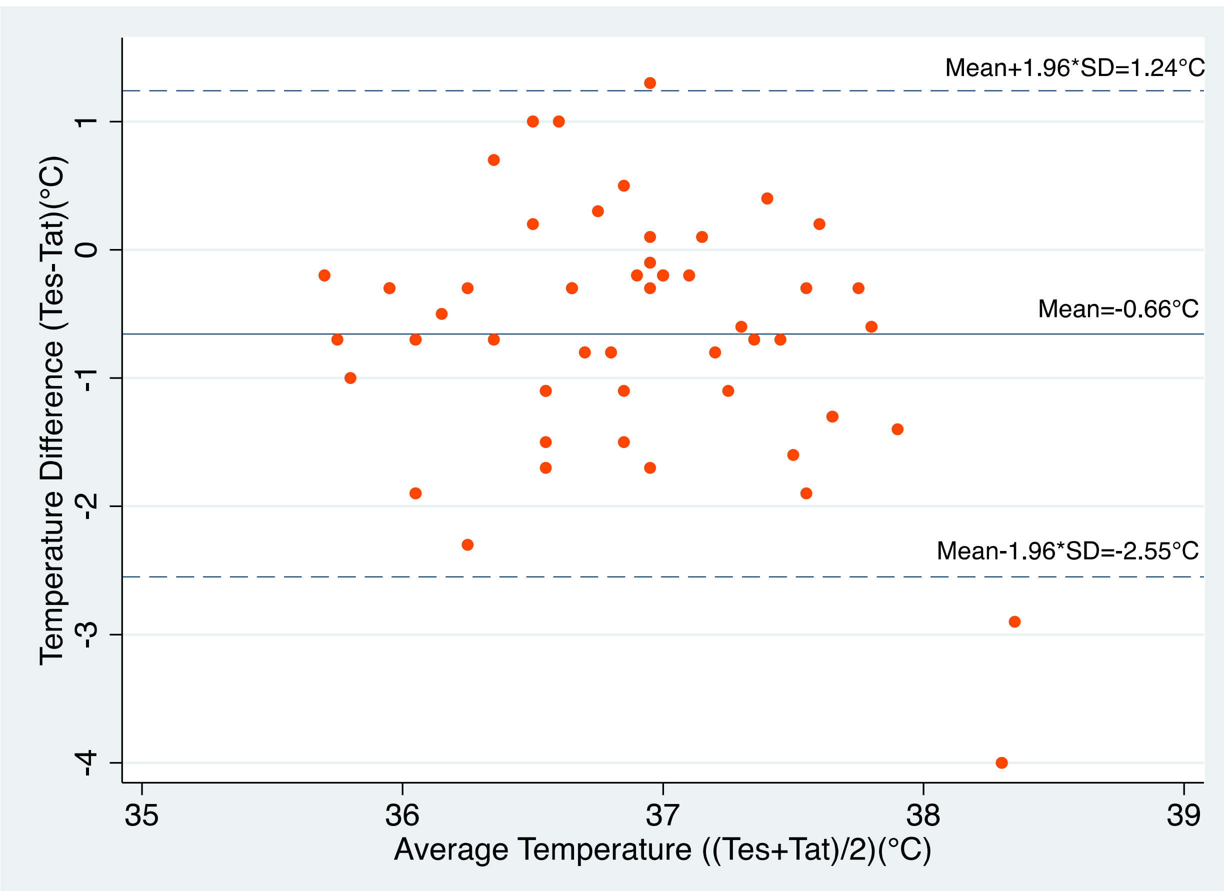

Figure 3. Bland-Altman Plot for Emergence

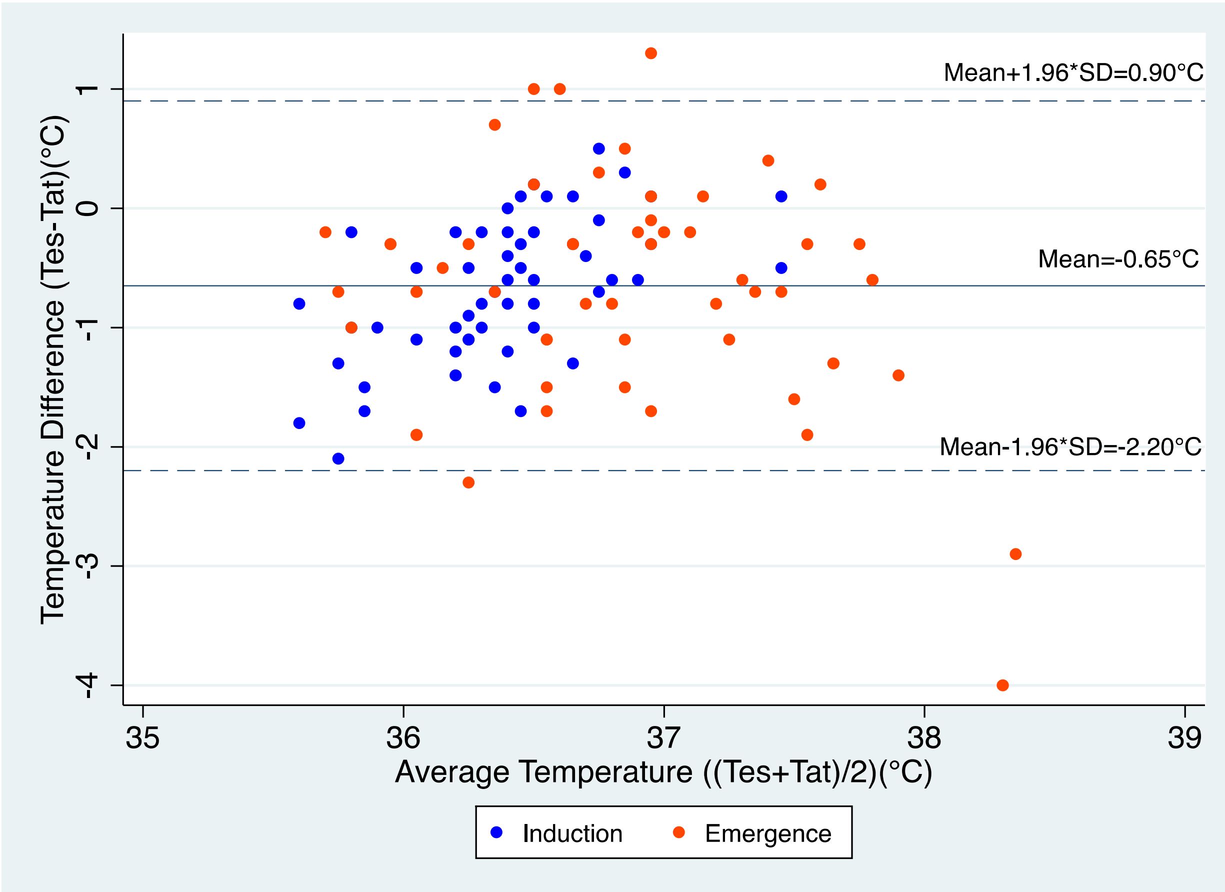

Figure 4. Combined Bland-Altman Plot for Induction and Emergence

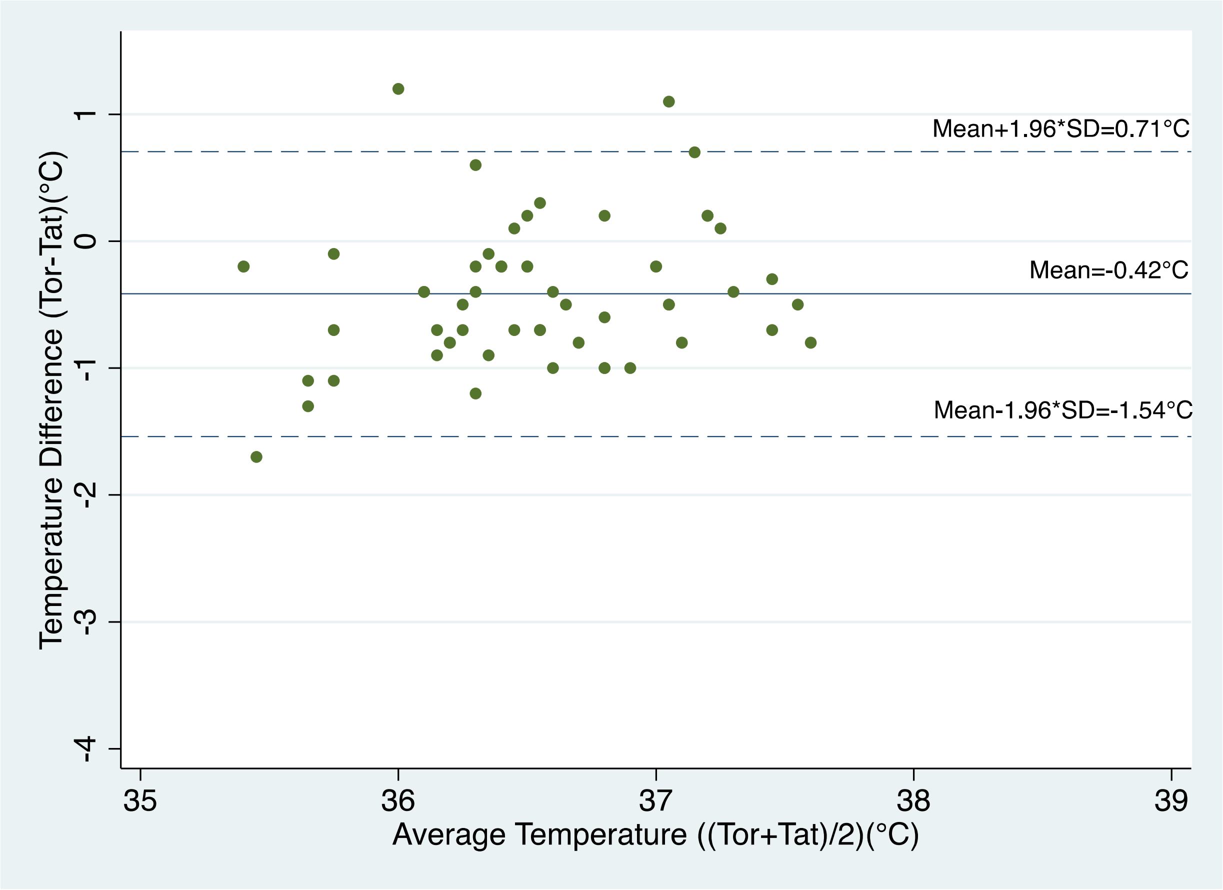

Figure 5. Bland-Altman Plot for PACU

When looking over the Bland-Altman plots, the graph for induction (Figure 2) looks less scattered and regular compared to the Bland-Altman plot at emergence (Figure 3), and it is difficult to see a relationship between the average and the difference of temperatures at the emergence plot compared to induction. To further explore the differences between these two plots, a combined graph of the two time points was created (Figure 4). This combined Bland-Altman plot of the data from induction and emergence shows significantly more induction points to the left and more emergence points at the right of the graph, showing that temperatures seem to be lower, in general, at induction compared to emergence.

The results of simple and multiple linear regression analyses are shown in Table 4 and 5. Unadjusted regression coefficients for surgical site (torso compared to neck) and the use of a muscle relaxant at emergence proved statistical significance. However, the significance of the regression coefficient for the use of muscle relaxants was diminished by adjusting for other covariates; only the torso compared to neck surgical site operations remained statistically significant ($p<0.05$). The mean difference between Tat and Tes at emergence for the participants receiving a muscle relaxant is significantly greater than participants not receiving a muscle relaxant (mean difference is -0.82℃ compared to -0.02℃, p = 0.0042). Although it was no longer statistically significant, there was the trend that the difference between Tat and Tes at emergence for neck surgery being lower when compared to other surgical sites (mean difference: neck -0.16℃, extremities -0.45℃, spinal -0.61℃, torso -1.09℃: $F(3, 45) = 2.61$, p=0.0633).

Table 4. Unadjusted Regression Results for the Difference between Temporal Artery Temperature and either Esophageal Temperature or Oral Temperature for Each Period

Factor	Induction Tat-Tes		Emergence Tat-Tes		PACU Tat-Tor	
	b	R square	b	R square	b	R square
Age (y)	0.0030[a]	0.0064	-0.0025[c]	0.0018	-0.0026[a]	0.0052
Gender (reference Female)		0.0001		0.0224		0.0442
Male	0.0103[b]		-0.2873[d]		-0.2368[b]	
Race (reference Caucasian)		0.0865		0.0538		0.0100
African American	0.4667[a]		0.3934[c]		0.1400[a]	
Others	-0.3633[a]		0.7535[c]		0.1650[a]	
Body Surface Area (BSA) (m^2)	0.1743[a]	0.0084	-0.0031[c]	0.0000	0.1854[a]	0.0102
ASA Score (reference 1)		0.0288		0.1313		0.0178
2	0.2950[a]		-0.5150[c]		-0.2550[a]	
3	0.3114[a]		-0.4938[c]		-0.2593[a]	
4	-0.0600[a]		-2.7400[c]		-0.3200[a]	
Surgical Site (reference Neck)				0.1480		0.0231
Torso			-0.9305[e]*		-0.1974[d]	
Spine			-0.4500[e]		-0.1455[d]	
Extremity			-0.2900[e]		-0.2545[d]	
Length of Surgery (min)			-0.0014[c]	0.0132	0.0006[a]	0.0066
Operating Room Temp (℃)	0.0457[a]	0.0157	-0.0958[c]	0.0230	-0.0903[a]	0.0659
Intravenous Fluid (mL)	-0.0005[a]	0.0390	-0.0002[c]	0.0223	-0.0001[a]	0.0129
Fentanyl (μg)	-0.0015[a]	0.0269	-0.0016[c]	0.0421	-0.0007[a]	0.0230
Use of Muscle Relaxant [n (%)]	0.3429[a]	0.0432	-0.8111[c]*	0.1194	0.2208[c]	0.0272
Use of Vasopressor [n (%)]	0.1683[a]	0.0134	-0.0021[c]	0.0000		
Midazolam (mg)					-0.0364[b]	0.0014

Propofol (mg)	-0.0001[b]	0.0018
		***p<0.05, [a] n=54, [b] n=53, [c] n=52, [d] n=51, [e] n=49**

Table 5. Adjusted Regression Results for the Difference between the Temporal Artery Temperature and either Esophageal Temperature or Oral Temperature for Each Period

Factor	Induction Tat-Tes b	Emergence Tat-Tes b	PACU Tat-Tor b
Age (y)	0.0412	0.0065	-0.0032
Gender (reference Female)			
Male	0.0655	-0.0866	-0.2643
Race (reference Caucasian)			
African American	0.4731	0.3914	0.5612
Other	-0.1852	0.7846	-0.0298
Body Surface Area (BSA) (m^2)	0.2198	0.4786	0.5574
ASA (reference 1)			
2	0.1566	-0.0460	-0.3560
3	-0.0325	-0.2189	-0.2388
4	-0.3945	-1.8280	0.6114
Surgical Site (reference Neck)			
Torso		-0.9716*	-0.2590
Spine		-0.4835	-0.1547
Extremity		-0.4772	-0.1717
Length of Surgery (min)		0.0025	0.0023
Operating Room Temperature (℃)	-0.0153	0.0036	-0.0997
Intravenous Fluid (mL)	-0.0005	-0.0000	-0.0000
Fentanyl (µg)	-0.0013	-0.0004	-0.0014
Use of Muscle Relaxant [n (%)]	0.1582	-0.6842	0.1188
Use of Vasopressor [n (%)]	0.1756	-0.1604	
Midazolam (mg)			-0.0148
Propofol (mg)			-0.0003
p-value for Full Model	0.7476	0.3794	0.6369
R-square for Multiple Linear Regression Model	0.1901	0.3888	0.3447
Number of Participants	53	48	48
			***p<0.05**

4.0 DISCUSSION

The level of agreement between central and peripheral indicators of temperature has been evaluated in many studies utilizing numerous devices and most studies conclude that the level of agreement between peripheral and central thermometers and the diagnostic accuracy of peripheral thermometers is poor.[18,20] Hence, peripheral thermometry is often considered a marginal screening tool for temperature abnormalities, particularly in settings where patients receive general anesthesia.[13,18] Thermometers that measure temperature from a central site are considered the gold standard because although peripheral thermometers confirm fever accurately, they do not adequately rule out fever and are less effective in detecting low-grade fevers, which is an important criteria to manage patients with an atypical presentation of infection.[18,20]

We did not find that the temporal artery thermometer values associated well with other thermometer devices, be it central or peripheral devices. Others have found poor agreement between temporal artery thermometers and comparing thermometry methods in adults; ultimately concluding the temporal artery thermometer should not replace common invasive or noninvasive thermometry methods.[16,21] The temporal artery thermometer's ability to detect fever and hypothermia has produced conflicting reports of accuracy and precision.[16,22] At temperature extremes, the Tat measurements may become affected by physiologic factors such as shivering, vasoconstriction, and diaphoresis seen during the various phases of fevers; and in perioperative areas specifically, where hypothermia is common, exposure to environmental temperature fluctuations and external heating devices can skew Tat measurements.[16] Researchers have found that the infrared temporal artery thermometer is flawed since it does not provide for sufficient accuracy and precision for body temperature measurements and has a poor ability to screen for fever and hypothermia, in both adults and children.[16,18,22]

Numerous studies confirm the inaccuracy of the temporal artery thermometer; however, there are various studies that found Tat is accurate, particularly in one study regarding colorectal and gynecological surgery.[23,24] In colorectal and gynecological surgical patients, researchers compared Tes with Tat and Tor and found that Tat and Tor both overestimated the Tes measurements, but with Tat being more accurate than Tor.[24] Although there was a statistical difference between the temperature measurements, the measurements were still within 0.4°C of the core esophageal measurement, which the researchers defined as clinically acceptable.[24] However, it is important to consider that this article did not look at the temperature extremes and the Tat's reliability in patients with fever or hypothermia, which could have influenced the conclusion of the paper and may explain the different results found in our study.

There are also reports on the implications of the temporal artery thermometer's accuracy in pediatric populations. In one study, Tat was compared to Tes and rectal temperatures in 80 children undergoing elective dental surgery and researchers concluded that the Tat measurements were comparable to the measurements from an esophageal and rectal thermometer.[25] In another study, researchers found that temporal artery thermometers are not an accurate indicator of core body temperature in children under five years old; however, it recommends its use as a quick screening tool for fevers in pediatric patients in busy healthcare environments at a fever cutoff of 37.7°C.[26] Additional research found that in pediatric patients undergoing anesthesia, temporal artery thermometers were accurate enough to replace nasopharyngeal thermometers for body temperature measurement.[27] These findings in pediatric populations are of interest when compared to the results found in adult-based studies. However, the better performance of the temporal artery thermometer in younger patients can be attributed to anatomical differences between adults and children. Adults have thicker skin over their superficial temporal artery with a thicker frontal bone, which could possibly act as a form of heat insulation that is coming from the well-perfused brain and allow for a temperature decrease of the superficial temporal artery skin temperature.[16] Also, adults may also have atherosclerotic temporal artery disease that can decrease the temperature of the temporal artery and cause an underestimation of Tat measurements.[16]

We found in our study that although temporal artery thermometers are more convenient than other methods of measuring temperature, there is variability between the temperature measurement when comparing it with Tes and Tor. Temperature differences between the temporal artery and the esophageal probe also shows to be greater in the lower end of the temperature range. This implies that temporal artery thermometers may overestimate the temperature of patients at colder temperatures. This is a concern since it is known that hypothermia is a problem in patients undergoing general anesthesia and there are many health risks associated with a lower body temperature that can lead to complications or even patient mortality.

Given the increased differences between Tat and Tes at colder temperatures and standard warming practices utilized intra-operatively, the cooler temperature at induction may be driving this relationship. The time that the patients are left unwarmed and surgically prepped with alcoholic chlorhexidine and betadine sterilizing products will ultimately facilitate heat loss. Consequently, it is likely that the patient would be much colder in the operating room at induction compared to emergence, when the patient has had time to warm up under convective warming devices.

In the emergence plot, when comparing these data to the trends in induction and emergence, it is difficult to see any kind of pattern between the points. However, the oral thermometer does eliminate the influence of peripheral vessel vasoconstriction seen in Tat, which is the body's response to being exposed to cold temperature. Vessel constriction will shunt blood closer to the core and this change can affect the measurement of the temporal artery thermometer since it uses the temperature of the skin's surface.

The influence of the use of muscle relaxants on the difference between Tes and Tat was seen at the time of emergence but not at the induction of anesthesia. This finding can be explained by the mechanism of thermogenesis. While the onset of action of the muscle relaxants have not made a significant impact on the patient's temperature at induction, at emergence the drug has had significantly more time to have reach its peak therapeutic effects for anesthesia care, but also time to cause side effects like decreased shivering and ability to generate heat. Length of surgery is an important consideration to be aware of as well. When the influential outlier points in the graph are excluded, the same conclusions can be made. Without the two influential points, length of surgery becomes significant in the analysis for being related to the difference between Tat and Tes from induction to emergence, which is an understandable considering warming practices intraoperatively. With a longer surgery, core temperatures have more time to adjust and progressively increase back to normothermia compared to shorter surgeries, which would indicate the importance of pre-warming patients preoperatively especially for shorter procedures.[3] Operations that required a torso surgical site compared to the neck were statistically significant in the results when considering the nature of the operation. With a larger surgical site at a central body location, there is decreased body surface to heat with hypothermia preventative measures like Bair Huggers with an increased body surface area that is prepped with alcoholic-based agents and exposed to the cold temperatures of the operating room.

In conclusion, all three Bland Altman plots show a mean difference less than 0, meaning there are significantly more negative points in the graphs. These consistently negative values show that temporal artery thermometry is generally overestimating actual body temperature, since Tes and Tor are being subtracted from Tat measurements when plotting the graphs. To summarize, the induction plot that included lower temperature data shows a pattern in the temporal artery thermometer's poor ability in detecting the surgical patients' colder temperatures. And when looking at the differences in Tes from induction to emergence, the use of muscle relaxants and the surgical site (torso compared to neck) caused a statistically significant result, suggesting the potential influence of these factors in the change in temperature between induction and emergence. These are all valuable pieces of information when translating this research to practice.

4.1 CLINICAL IMPLICATIONS

Generally, the study showed that below 37-38˚C, temporal artery thermometers showed a greater difference from a standard core temperature measurement at lower temperatures. In a systematic review and meta-analysis of 37 articles (5,026 subjects) looking specifically at the temporal artery thermometer, it was found that the temporal artery thermometer is not accurate enough to replace more invasive methods.[28] A subgroup analysis of this study showed a trend towards an underestimation of the temperature in patients who were febrile.[28] When Tat was exclusively compared to a pulmonary artery catheter temperatures (PAT) in febrile patients, there was a proven accuracy of Tat compared to the PAT at temperatures above 38˚C; however, with poor precision.[23] The study found that Tat measurements were accurate with a 0.5°C lower mean temperature than

PAT, but Tat had a 25% frequency in lack of precision, which was influenced by the provder's technique and the cleanliness of the temporal artery thermometer's prober over time.[23] Researchers attribute this lack of precision to factors such as diaphoresis, vasopressor medications, and environmental airflow, cleanliness of the temporal artery thermometer lens, and operator use.[23]

When considering the temporal artery thermometer's use in practice, many healthcare providers may not be reading through the manufacturer's recommendations. However, improper use may skew the results. First, the thermometer should be used on the side of the head exposed to the environment—anything that could be covering the area, including hair, hats, bandages, or wigs, can cause a falsely high reading.[17] The thermometer is also not designed to be used for the side of the face, which many healthcare professionals may believe considering the anatomy of the artery. [17] The artery is about a milliliter below the skin at the midline of the forehead; however, the artery is much deeper at the side of the face, which could cause a misleadingly low temperature reading.[17] When retaking a temperature on a patient, it is also recommended to wait 30 seconds to avoid excessive skin cooling.[17] Other factors such as sweating, which can cause heat loss, should be noted before taking Tat. The temporal thermometer will give a low reading as a result of sweating and excessive cooling so the manufacturer recommends to not wipe the sweat, but instead follow a separate set of steps to obtain a more accurate reading, which is not obvious to many healthcare providers.[17] Environmental effects can also cause an inaccurate temperature reading if the thermometer is not properly adjusted to the room's temperature, so it is recommended to allow for 30 minutes for the thermometer to acclimate before using it when it is taken from a cold to a hot room, or vice versa.[17] When there is an inaccurate temperature, the manufacturer recommends using it behind the ear lobe; however, even the company includes a note that the artery behind the ear may not be accurate, but sweating is less of an influential factor so it could provide a good reflection of body temperature.[17] For these reasons, it is important to make sure that when the temporal artery thermometer scanner is used, the healthcare provider is properly instructed on its use and understands the different factors that may affect a reading and how to troubleshoot these issues.

When applying these conclusions to practice, there is a question whether there is a time when the benefit of convenience offered by the temporal artery thermometer could be advantageous over the accuracy of the thermometer when compared to core body temperature measurement. For a relatively healthy patient or in emergent circumstances, the efficiency of the temporal artery thermometer may provide to be an incredibly valuable medical tool. However, for the variable surgical patient receiving general anesthesia, the use of a temporal artery thermometer is not the best tool for this population because of its poor ability in detecting the common perioperative problem of hypothermia.

4.2 LIMITATIONS

Limitations of the study include several confounding variables. We did not collect data on the length of esophageal probe placed into the patient—depending on who inserted the probe and the individual patient, how far the esophageal probe was inserted is varied and the deeper the probe was in the esophagus, the higher the temperature would be. Secondly, oral thermometers are also difficult for the patient to hold in their mouth since they may not be completely alert when they go into the PACU. There is also considerable variability in patient age and type of procedure, thus our sample lacks homogeneity. Lastly, there are not many febrile patients in the sample hence we were not able to test the efficacy in that population.

4.3 CONCLUSION

In summary, the temporal artery thermometer is a quick and convenient tool and could be useful certain situations. However, regarding the perioperative patient population studied in this research, it is not an accurate tool in identifying patients that develop hypothermia during the perioperative period. Considering the potential risks of obtaining inaccurate temperatures in a surgical patient, such as perioperative hypothermia and malignant hyperthermia, the use of a central body temperature monitoring device like an esophageal probe should be emphasized as a priority especially in operations that use larger surgical sites and require the use of muscle relaxants.

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