

Temporal Thermometry Fails to Track Body Core Temperature during Heat Stress

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ABSTRACT

LOW, D. A., A. VU, M. BROWN, S. L. DAVIS, D. M. KELLER, B. D. LEVINE, and C. G. CRANDALL. Temporal Thermometry Fails to Track Body Core Temperature during Heat Stress. *Med. Sci. Sports Exerc.*, Vol. 39, No. 7, pp. 1029–1035, 2007. **Purpose:** The aim of this study was to assess the accuracy of temporal scanning thermometry in monitoring internal temperature increases during passive heating. **Methods:** Sixteen subjects (5 males and 11 females) underwent a whole-body passive heat stress (water-perfused suit) to increase internal temperature. Temperatures were obtained with a temporal scanner and with an ingestible-pill telemetry system that tracks intestinal temperature. Temperatures were recorded while subjects were normothermic (34°C water-perfusing suit) and every 10 min during passive heating (48°C water-perfusing suit). **Results:** Heart rate (ECG), mean skin temperature (weighted six-site average), skin blood flow (laser Doppler flowmetry), and sweat rate (capacitance hygrometry) were all significantly elevated at the end of heating (all $P < 0.001$). Pre-heat stress temporal-derived temperature was not different from intestinal temperature (36.98 ± 0.09 vs $37.01 \pm 0.09^\circ\text{C}$, respectively, $P = 0.76$). However, after 30 min of heating (the greatest duration of heating completed by all subjects), temporal-derived temperature decreased to below the pre-heat stress baseline (-0.22 ± 0.11), whereas intestinal temperature increased by $0.39 \pm 0.07^\circ\text{C}$ ($P < 0.001$ between the two methods). After 50 min of heating ($N = 11$), intestinal-derived internal temperature increased by $0.70 \pm 0.09^\circ\text{C}$, whereas temporal-derived temperature decreased by $0.29 \pm 0.10^\circ\text{C}$ ($P < 0.001$). The group average (\pm SEM) R^2 and slope between the two methods were 0.29 ± 0.08 and -0.34 ± 0.14 , respectively. **Conclusion:** These results demonstrate that temporal scanning does not track internal temperature, as measured via intestinal temperature, during passive heating. Given these findings, it is recommended that this technique not be used to assess temperature in hyperthermic diaphoretic subjects. **Key Words:** HYPERTHERMIA, FEVER, INTESTINAL TEMPERATURE, MEASUREMENT ERROR

Regulation of internal (core) body temperature within a narrow range is vital for the well-being of humans. Consequently, the accurate assessment of body temperature is critical for medical practitioners, athletic trainers, etc. Pathological conditions that result in fever, as well as elevated environmental temperatures and/or exercise, can raise core temperature to dangerously high levels, resulting in reduced physical work capacity, heat illness, and death (5,6). Therefore, the precise measurement of core

temperature in these situations is vital for the early detection and diagnosis of such pathological conditions.

A newly proposed, noninvasive method of internal temperature assessment, temporal scanning thermometry, has been developed for both clinical and home use; the primary advantages cited for this method are its simplicity and quick results (24). This method involves the use of an infrared scanner that detects the highest temperature of forehead skin, presumably from the temporal artery (13). From this value, the device estimates core temperature using a proprietary algorithm that incorporates compensation for the ambient temperature and “standard” temperature gradients from the skin to the body’s core.

Since its introduction, a number of hospitals and clinics have switched to temporal scanning thermometry as their primary method of temperature measurement. For instance, a systematic survey of 101 hospitals in Texas, listed on the Web site http://dmoz.org/Health/Medicine/Facilities/Hospitals/North_America/United_States/Texas/, identified that approximately 30% use a temporal scanning device in

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at least one of their clinical departments. Similarly, these devices are used in the medical tent of the Boston Marathon to evaluate internal temperatures of runners receiving medical care (reported on the Web page <http://www.exergen.com/medical/pressrel/april2005.htm>). However, there have been conflicting findings regarding the accuracy of temporal scanners as a tool for measuring core temperature (7,21,27). For example, studies conducted on adult patients have concluded that the temporal artery thermometer does (18) and does not (7,27) concur with rectal/pulmonary artery temperature measurements. These latter studies were conducted in febrile patients, whereas the former study recorded temperatures of subjects in the normothermic range. These observations suggest that when core temperature is elevated, temporal scanning may not provide a good index of core temperature. A key limitation of prior assessments of temporal scanning devices is the absence of a change in temperature being imposed on the subject/patient, as would occur during the onset of a fever, during exposure to warm environments, and during sustained exercise. Thus, it is unknown whether this device accurately tracks changes in internal temperature. Therefore, the aim of this study was to compare responses from a clinical model of a temporal scanner thermometer with intestinal temperature during progressive increases in core temperature in healthy volunteers.

METHODS

Subjects. Sixteen subjects (five males and 11 females) participated in this study (mean \pm SD age 39 ± 10 yr, height 170 ± 11 cm, weight 76 ± 18 kg). All subjects were healthy and free from cardiovascular and metabolic diseases. Subjects refrained from alcohol and exercise for 24 h before the study and refrained from caffeine for 12 h before the study. Institutionally approved written informed consent was obtained from all participants before they were enrolled in the study.

Measurements. Each subject was dressed in a water-perfused, tube-lined suit (Med-Eng, Ottawa, Canada) that permitted the precise control of skin and core temperature by changing the temperature of the water perfusing the suit (4,23). The suit covered the entire body surface, with the exception of the hands, face, feet, and either one arm or one leg. Mean skin temperature was measured via the electrical average of six thermocouples attached to the skin under the water-perfused suit on the lateral gastrocnemius, anterior quadriceps, lower and upper back, abdomen, and upper chest (28). Heart rate was obtained from an electrocardiogram (Agilent, Munich, Germany) interfaced with a cardi tachometer (CWE, Ardmore, PA). Intermittent arterial blood pressure was measured from the brachial artery by electrospphygmomanometry (SunTech Raleigh, NC). Mean arterial pressure (MAP) was calculated as one-third pulse pressure plus diastolic pressure. Skin blood flow and sweat rate ($N = 9$) were measured from the arm or leg that was not

exposed to the tube-lined suit, to confirm that the heat stress was of sufficient magnitude to evoke efferent thermoregulatory responses. Skin blood flow was measured using a multifiber laser Doppler flowmetry probe (Perimed, North Royalton, OH) and indexed as cutaneous vascular conductance (CVC; ratio of laser Doppler flux to MAP). Sweat rate was measured from an area adjacent to the laser Doppler probe via capacitance hygrometry (Vaisala, Woburn, MA).

Core temperature was indexed from an ingestible-pill telemetry system (HQ Inc., Palmetto, FL). In this system, the subject swallows a small, disposable, silicon-coated pill that contains a crystal quartz oscillator, which transmits a low-frequency radio wave to an external receiver (17,20). The frequency of the radio wave varies proportionally to the temperature of the pill, and manufacturer calibration of the pill allows the frequencies recorded to be related to temperature. In our study, subjects swallowed the pill on arrival at the laboratory, and data collection did not begin until at least 90–120 min after ingestion. The ingestible-pill telemetry system approximates esophageal temperature very closely and has been reported to be superior to rectal temperature as an index of core temperature during both passive heating and cooling and during active elevations in core temperature via exercise (15,20,26). This system is being used clinically, particularly in collegiate and professional athletics (8,10,12), and also in astronauts (11). Temporal-derived temperatures were obtained using the clinical version of a temporal scanner (TemporalScanner TAT-5000, Exergen, Watertown, MA). Investigators were trained on the appropriate use of the device by a representative from the manufacturer. Instructions accompanying the device (9) were strictly followed. Scans were performed as the lens of the instrument traversed from the midline of the forehead to the lateral hairline, as well as behind the ear as specified by the manufacturer for diaphoretic individuals. At the onset of sweating, all subsequent scans were performed after sweat was removed by gently wiping the area dry before each measurement. The scanning device was cleaned and maintained as specified in the instructions. Temperatures from both devices were obtained during a normothermic baseline period and every 10 min during heat stress. Three readings were obtained from each device, and the mean of each set of recordings was used for data analysis.

Protocol. All experiments were performed in a temperature-controlled laboratory ($26 \pm 1^\circ\text{C}$) in the morning or early afternoon at least 2 h postprandially. Data were obtained with the subject in a supine position. Normothermic baseline measurements were recorded while perfusing the suit with 34°C water. After normothermic data collection, the heat stress ensued by perfusing 48°C water through the suit until internal temperature increased by approximately 0.7°C (according to the ingestible-pill system). On completion of the whole-body heat stress, cool water was perfused through the suit, and the protocol ended.

Data analysis. With the exception of the intestinal- and temporal-derived temperatures, data were sampled at 50 Hz via a data-acquisition system (Biopac System, Santa Barbara, CA). One-minute averages of thermoregulatory and hemodynamic responses, with the exception of the core temperature measurements, were calculated from the final minute of normothermic baseline and whole-body heating periods. Differences in skin blood flow, heart rate, blood pressure, and sweat rate between normothermia and at the end of heat stress were evaluated using a paired *t*-test. Temporal scanning and intestinal measures of core temperature were evaluated using a two-way ANOVA, with main effects of measurement device and time. The relationship between values from the ingestible-pill telemetry system and temporal scanning for each subject were assessed using linear regression analysis. Differences in readings between the devices were also assessed using Bland–Altman limits of agreement (3,19). Bland–Altman limits of agreement allow the calculation of the systematic bias and the random variation (the closer the random variation to zero, the lower the random variation between the two devices) between two different measurement methods and provide the limits within which 95% of the differences for two sets of measurements are expected to lie (the closer these limits are to zero, the better the agreement between the two devices). Statistical analysis was performed using SigmaStat (Chicago, IL). All values are reported as means ± SEM. A *P* value < 0.05 was considered statistically significant.

RESULTS

Four of the 16 subjects achieved the target core temperature at 30 min, one subject at 40 min, seven subjects at 50 min, and four subjects at 60 min. Cardiovascular and thermoregulatory responses during normothermia and at the end of heat stress are presented in Table 1. Heart rate ($T_{15} = 9.95, P < 0.001$), mean skin temperature ($T_{15} = 20.42, P < 0.001$), CVC ($T_{15} = 6.38, P < 0.001$), and sweat rate ($T_{15} = 20.42, P < 0.001$) were all significantly elevated by the end of heat stress. MAP did not change during heat stress ($T_{15} = 1.61, P > 0.05$). Ambient temperature was held constant ($26 \pm 1^\circ\text{C}$) throughout each experiment.

Core temperature readings from the two devices are displayed in Figure 1. There was a significant main effect of

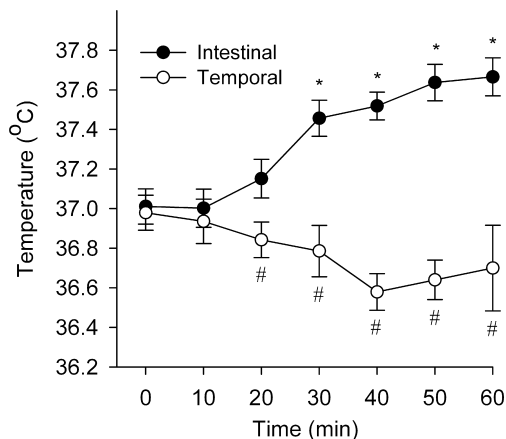


FIGURE 1—Intestinal- (●) and temporal-derived (○) temperature responses during passive heating. # *P* < 0.001 vs intestinal temperature; * *P* < 0.05 vs baseline. *N* = 15 at 30 min, *N* = 12 at 40 min, *N* = 11 at 50 min, and *N* = 4 at 60 min.

measurement method ($F_{1,82} = 141.21, P < 0.001$). Temporal scanning-derived temperature was not different from intestinal temperature at baseline (36.98 ± 0.09 vs $37.01 \pm 0.09^\circ\text{C}$, respectively, $P = 0.76$) and after 10 min of heat stress. Thereafter, temperature from the temporal scanner was significantly lower relative to intestinal temperature, exhibiting a decrease in temperature throughout the remainder of the heat stress ($F_{6,82} = 13.46, P < 0.001$). Evaluation of the change in temperature from baseline revealed that with the temporal scanner, the recorded temperature decreased by $0.29 \pm 0.10^\circ\text{C}$ at 50 min of the heat stress, and at the same time, the average intestinal temperature increased by $0.70 \pm 0.09^\circ\text{C}$ ($F_{1,67} = 152.90, P < 0.001$ between these values). A similar divergence of responses

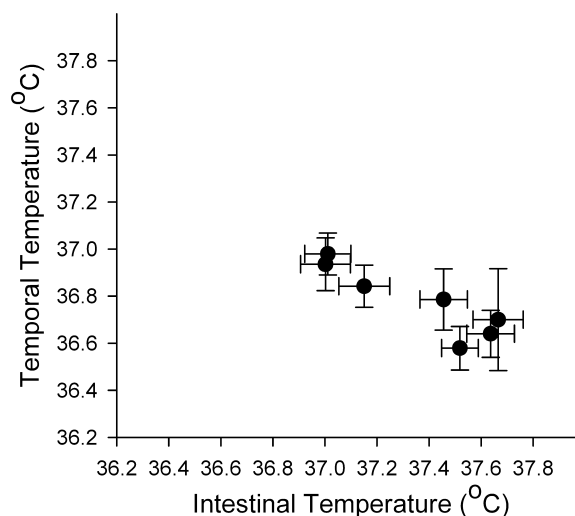


FIGURE 2—Averaged responses between intestinal- and temporal-derived temperatures during passive heating. Data depict pre-heat stress baseline and responses at each 10-min interval throughout the heat stress. Data in this format were evaluated for each subject via linear regression. Averaging of those individual responses resulted in an R^2 of the relationship between the increase in intestinal- and temporal-derived temperatures of 0.29 ± 0.08 , with a slope of -0.34 ± 0.14 .

TABLE 1. Mean (± SEM) thermoregulatory and cardiovascular responses at the end of normothermic baseline conditions (normothermia) and during heat stress.

	Normothermia	Heat Stress
Mean skin temperature (°C)	34.6 ± 0.1	37.8 ± 0.1*
Heart rate (bpm)	66 ± 4	87 ± 5*
Mean arterial blood pressure (mm Hg)	85 ± 2	82 ± 3
Δ sweat rate (mg·cm ⁻² ·min ⁻¹)	—	0.53 ± 0.07†
Cutaneous vascular conductance (AU·mm Hg ⁻¹)	0.29 ± 0.03	1.10 ± 0.14*

* *P* < 0.001 vs normothermia.
† *N* = 9.

was evident for the change in temperature (i.e., delta) between devices (data not shown). Averaged (\pm SEM) responses between intestinal- and temporal-derived temperatures at baseline and at each 10-min interval throughout passive heating are presented in Figure 2. Data in this format were evaluated for each subject via linear regression. The average (\pm SEM) of the individual R^2 and slopes of the intestinal- and temporal-derived temperature relationships were 0.29 ± 0.08 and -0.34 ± 0.14 , respectively. Together, these data clearly indicate the lack of agreement between these devices; this lack of agreement is attributable to decreased temperature readings from the temporal scanning device as intestinal temperature is elevated during the heat stress.

At 10-min increments, both devices were used to obtain temperature in triplicate. To evaluate the degree of variability among these repeated measures, the standard

deviation of the three temperature readings was calculated, and for each device, this value was averaged throughout the entire heat stress. The average standard deviation of the triplicate readings for the intestinal temperature device ($0.02 \pm 0.004^\circ\text{C}$) was less than the average standard deviation of the triplicate measures for the temporal-derived temperature ($0.15 \pm 0.013^\circ\text{C}$; $P < 0.001$). This observation suggests that the variability between repeated readings for the temporal-derived device was significantly greater than that of the intestinal temperature-derived device.

Data from the Bland–Altman analysis are presented in Figure 3. The mean difference (\pm random variation) between temporal scanning and intestinal temperature readings at baseline was minimal ($0.03 \pm 0.66^\circ\text{C}$). Thereafter, this difference greatly increased as internal temperature was progressively elevated, resulting in a difference of $1.00 \pm 0.62^\circ\text{C}$ after 50 min of heating, reflecting the

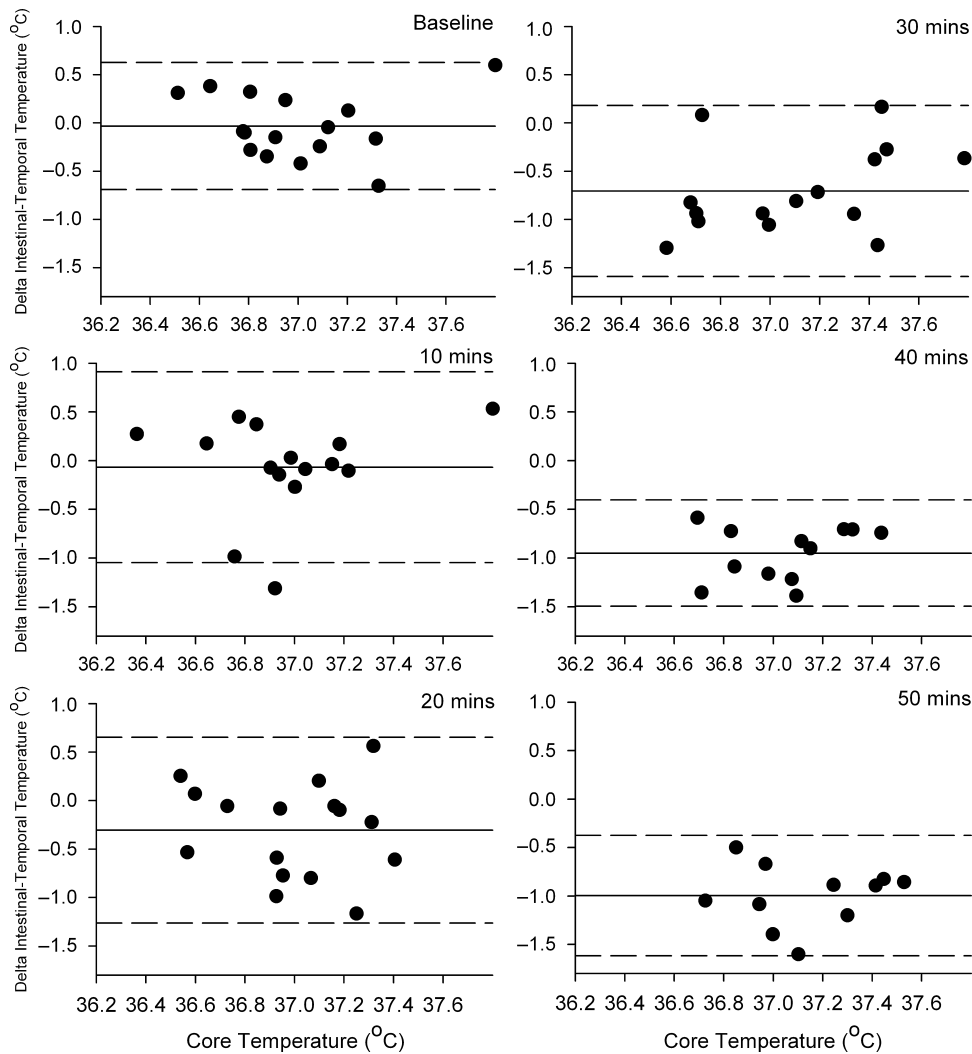


FIGURE 3—Bland–Altman plots of intestinal- and temporal-derived temperatures at normothermic baseline and during passive heating. *x*- and *y*-axis scales are the same in each panel for comparative purposes. *Upper and lower horizontal dashed lines* are the upper and lower limits of agreement, respectively (the limits within which 95% of the differences for two sets of measurements are expected to lie; the closer these limits are to zero, the better the agreement between the two devices). *The solid middle line* is the mean difference (systematic bias) between the two devices. *The x-axes* are the average of the intestinal- and temporal-derived temperatures.

divergence of the recordings from the two devices (e.g., an increase in intestinal temperature and a decrease with temporal-derived temperature). At baseline, the upper and lower limits of agreement between the two devices were 0.63 and -0.69°C . As the heat stress progressed, the lower limit decreased further from zero and the upper limit became negative, such that by 50 min of heat stress, these values were -1.62 and -0.38°C , respectively. Overall, these data reflect very poor agreement between the two devices and a lack of convergence of temperature readings during heat stress.

DISCUSSION

The aim of this study was to compare internal temperature as identified by temporal scanning thermometry to intestinal temperature (using an ingestible-pill telemetry system) during carefully controlled passive heating-induced increases in core temperature in healthy subjects. Intestinal temperature was used as the reference standard for core temperature assessment because it has been shown to concur with esophageal temperature during active and passive heating-induced elevations in core temperature (15,20,26). Consistent with a previous study (18), mean temperature was not different between devices before the heat stress. However, as the heat stress progressed, temperature was not accurately assessed with the temporal scanning device; this device detected an approximately 0.2°C decrease in temperature, whereas intestinal temperature increased by approximately 0.7°C . These responses resulted in a poor (and, in fact, negative) relationship between temporal scanning-derived and intestinal temperatures. These observations indicate that the temporal scanning device does not provide a good index of core temperature during mild passive heat stress-induced elevations in core temperature.

Despite widespread clinical use of the temporal scanning devices for the assessment of temperature, relatively few studies have evaluated the accuracy of this method in adults (7,18,27). Some of these studies have raised questions about the accuracy of these devices (7,27). Dybwick and Nielsen (7) report that the temporal artery scanner detected fever in only 33 of 70 patients, with *fever* defined as a rectal temperature of at least 38°C . These authors propose that the sensitivity of the temporal artery thermometer was “too low to recommend its use in adult intensive care patients.” Suleman et al. (27) report a poor correlation ($R^2 = 0.3$) between the temporal artery scanner and pulmonary artery temperature in adult patients who developed a mild fever as indicated by a pulmonary artery temperature of at least 37.8°C . Ostrowsky et al. (21) have expressed concerns that fevers were missed in their hospital after the introduction of temporal artery scanner devices. Finally, Myny et al. (18) have evaluated differences in temperatures obtained with a temporal scanner and the pulmonary artery in adults.

Although the mean difference in temperature between these methods was only 0.14°C , a standard deviation of this difference of 0.51°C raises serious questions regarding the variability of this measure and, thus, the variability of the scanning device. The present study adds new, important information to these previous studies by evaluating internal temperature during changes in temperature induced by passive heat stress. Importantly, the findings from the present study similarly question the accuracy of the temporal scanner in correctly identifying internal temperature in adults.

A recognized limitation of the temporal thermometer is that cooling of the skin associated with sweating can interfere with temperature measurement. We measured significant increases in forearm/leg sweat rate (Table 1), and visible sweating was observed on most subjects' foreheads. To address this issue, before each measurement, sweat was removed by gently wiping the area to be scanned dry (per the manufacturer's instructions). Secondly, we followed the manufacturer's recommendation for diaphoretic subjects by scanning the area behind the ear in addition to the forehead-temporal region. Thus, it is unclear whether the reduction in temperature as measured from the temporal scanner during passive heating was attributable to sweating accompanying the heat stress or from some other source. Regardless, the temporal scanner is currently being used in the medical tent at the Boston Marathon (see the Web page <http://www.exergen.com/medical/pressrel/april2005.htm>), presumably on profusely sweating runners. Given the present findings, the potential for this device to greatly underestimate actual temperature and its use at this and perhaps other athletic events is of serious concern to the authors. Moreover, should a more severe heat stress have been used in the present study, resulting in greater elevations in core temperature similar to those typically occurring during strenuous exercise, it is expected that differences between intestinal- and temporal-scanning thermometry readings would have persisted. Consistent with this thought, in 5 of the 16 subjects evaluated, the heat stress continued until intestinal-derived internal temperature had increased by approximately 1°C relative to the pre-heat stress baseline (36.83 ± 0.14 to $37.79 \pm 0.10^{\circ}\text{C}$; data not shown). At the same time point, temporal scanning-derived readings continued to report a *decrease* in temperature (36.85 ± 0.08 to $36.68 \pm 0.22^{\circ}\text{C}$) from the pre-heat stress baseline.

Another potential limitation of the use of the temporal scanning device is the reported assumption that the device is actually measuring the temperature of the temporal artery (U.S. patent 6292685 (9)). The temporal scanner has no way of identifying the location of the temporal artery. Rather, the device, using infrared thermometry, takes rapid samples of temperature as the device is drawn across the patient's forehead; it is presumed that the highest temperature reading originates from the temporal artery. However, if the highest temperature reading occurs in an area remote

from the temporal artery, the device will use that reading in the calculation of internal temperature. The recommendation that temperature be assessed behind the ear for diaphoretic subjects further demonstrates that this device does not rely solely on the temporal artery for its measure, because the temporal artery is not located behind the ear.

Using ambient temperature and the highest temperature on the forehead's surface (or from behind the ear), the temporal scanning device estimates core temperature using a proprietary algorithm that incorporates the following equation (U.S. patent 6292685):

$$T_{\text{CORE}} = (1 + (h/pc))(T_{\text{SK}} - T_{\text{AMB}}) + T_{\text{AMB}}$$

where T_{CORE} = core temperature, T_{SK} = highest skin (or surface) temperature, T_{AMB} = ambient temperature, h = the heat transfer coefficient between the target surface and ambient temperature, p = perfusion rate, and c = specific heat of blood. According to this formula, as indicated by the manufacturer, the difference between surface and ambient temperature is weighted according to the approximation of h/pc at the temporal artery, which varies with target surface temperature. As part of this formula, it is assumed that flow through the temporal artery (presumably p) is high and relatively constant, as proposed by the manufacturer (U.S. patent 6292685 (9)). We are unaware of any documented evidence that flow through the temporal artery is constant. It is important to emphasize that flow through any artery will be greatly affected by changes in the diameter of that vessel and by changes in vascular resistance downstream from the vessel. In contrast to the manufacturer's claim that flow through the temporal artery is relatively constant, published findings demonstrate the opposite. Specifically, there is clear evidence that changes in temporal artery blood flow occur in association with migraine headaches (1,2,14,22,29) and that isolated human temporal arteries constrict in the presence of adrenergic agents and dilate in the presence of neuropeptides (1,16,22,25,29,30). Thus, despite the manufacturer's claims, wide differences in temporal artery flow can occur, and these changes in flow have the potential to cause large differences in temperature as detected by the scanning device over this artery. Importantly, it is likely that an inaccurate reading will occur under conditions where blood flow to this area may be changing, such as vasoconstriction associated with migration from a nonfever to a fever state, vasodilation during transition from a fever to a nonfever state, and/or administration of vasoactive agents. Finally, a number of factors, including skin blood flow, body insulation, and ambient

temperature, can affect skin temperature without changing core temperature; this likely will cause errors in the estimation of core temperature according to this formula. For example, the manufacturer recommends that each device should remain, for a prolonged period of time, in the environment where temperature is to be taken, to allow the device to stabilize with ambient temperature. However, if a patient moves to a different room with a different ambient temperature and has his or her temperature immediately measured with this device, there is an increased potential for an error in the reading, because skin temperature will remain affected by the previous room's ambient temperature.

Clinical implications. By definition, *fever* is an elevation in internal temperature, which is a key clinical indicator of an infection. Exercise, as well as exposure to high ambient temperatures, can increase core temperature to precariously high levels, potentially culminating in severe heat illness and death (5,6). The use of an accurate technique for the clinical assessment of body temperature in these and related conditions is critical for the appropriate evaluation of the patient. Inaccurate temperature readings ultimately can lead to incorrect diagnosis, delay of appropriate treatment, and subsequent permanent injury or death. The present data demonstrate that the temporal scanning technique does not accurately track increases in core temperature during passive heating. This observation strongly suggests that patients might be misdiagnosed if the user solely relies on these devices as an accurate indicator of internal temperature.

CONCLUSION

Consistent with prior assessments of core temperature obtained from non-heat-stressed subjects (18), temporal scanning-derived temperatures provided comparable results relative to intestinal temperature, although the variability between these measures was pronounced. However, the temporal scanner did not accurately monitor core temperature during passive heating-induced elevations in internal temperature. Given the wide use of temporal thermometers in hospital, clinical, athletic, and home settings, the present results raise serious health-related concerns regarding the use of these devices to accurately measure internal temperature.

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