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original research

Comparison of Gastrointestinal and Rectal Temperatures During Recovery After a Warm-Weather Road Race

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Context: It has been well established that gastrointestinal temperature (T_{GI}) tracks closely with rectal temperature (T_{REC}) during exercise. However, the field use of T_{GI} pills is still being examined, and little is known about how measurements obtained using these devices compare during recovery after exercise in warm weather.

Objective: To compare T_{GI} and T_{REC} in runners who completed an 11.3-km warm-weather road race and determine if runners with higher T_{GI} and T_{REC} present with greater passive cooling rates during recovery.

Design: Cross-sectional study.

Setting: Field.

Patients or Other Participants: Thirty recreationally active runners (15 men, 15 women; age = 39 ± 11 years, weight = 68.3 ± 11.7 kg, body fat = 19.2% ± 5.0%).

Main Outcome Measure(s): The T_{GI} and T_{REC} were obtained immediately after the race and during a 20-minute passive rest at the 2014 Falmouth Road Race (heat index = 26.2°C ± 0.9°C). Temperatures were taken every 2 minutes during passive rest. The main dependent variables were mean bias and limits of agreement for T_{GI} and T_{REC}, using Bland-Altman analysis, and the 20-minute passive cooling rates for T_{GI} and T_{REC}.

Results: No differences were evident between T_{GI} and T_{REC} throughout passive rest ($P = .542$). The passive cooling rates for T_{GI} and T_{REC} were 0.046 ± 0.031°C·min^{-1} and 0.060 ± 0.036°C·min^{-1}, respectively. Runners with higher T_{GI} and T_{REC} at the start of cooling had higher cooling rates ($R = 0.682$, $P < .001$ and $R = 0.54$, $P = .001$, respectively). The mean bias of T_{GI} during the 20-minute passive rest was –0.06°C ± 0.56°C with 95% limits of agreement of ±1.09°C.

Conclusions: After participants completed a warm-weather road race, T_{GI} provided a valid measure of body temperature compared with the criterion measure of T_{REC}. Therefore, T_{GI} may be a viable option for monitoring postexercise-induced hyperthermia, if the pill is administered prophylactically.

Key Words: hyperthermia, body temperature, temperature measuring devices, validity

Key Points

- Compared with rectal temperature, gastrointestinal temperature provided a valid measure of body temperature during passive rest after intense exercise in warm weather.
- Due to the constraints associated with obtaining gastrointestinal temperature (eg, timing of pill ingestion, potential for the pill to malfunction or pass), rectal temperature remains the recommended measure for assessing patients with possible exertional heat stroke.

Body temperature during and after exercise has been studied to quantify the level of physiologic strain experienced by exercising individuals.[1] The rise in body temperature during physical activity is reported to have adverse effects on athletic performance[2–5] and may also lead to exertional heat illness, such as exertional heat stroke (EHS), if the heat load exceeds the individual's thermoregulatory capacity.[6] Previously, the validity of various modes of body temperature assessment, such as esophageal, rectal, gastrointestinal, temporal, axillary, aural, and oral, for use in exercising individuals has been examined.[7–12]

Pulmonary artery temperature is considered the gold standard for temperature assessment in the laboratory and clinical settings.[13] However, this method lacks practical application in the field and athletic settings due to the invasiveness of obtaining the temperature measure. Rectal thermometry has been established as a valid and practical method of body temperature assessment in exercising individuals and is considered the gold standard for recognizing EHS.[12,14] Rectal thermometry compares favorably with pulmonary artery temperature assessment and has been extensively tested against other temperature devices in laboratory, field, and surgical settings.[7,8,13]

The validity of another body temperature assessment method, gastrointestinal thermometry, has been investigated in many laboratory settings.[8–10,15–17] Although these results suggest that gastrointestinal thermometry produces measurements similar to those of rectal thermometry, Savoie et al[18] recently reported that gastrointestinal temperature (T_{GI}) was not comparable with rectal temperature (T_{REC}) within a predetermined acceptable range (systematic bias <0.1°C and 95% limits of agreement [LOA] within ±0.40°C) when cold beverages (4°C) were consumed during a 21.2-km running time trial to maintain body mass loss under 1% in the heat (ambient temperature ~30°C, relative humidity = 44%). This suggests that more studies are warranted to explore the application and interpretation of T_{GI} in field settings.

When rectal and gastrointestinal thermometry were examined for validity in exercise scenarios, the measurements were taken during or at the end of exercise. However, to our knowledge, only a few researchers have compared validated temperature devices (T_{GI} or T_{REC} or both) during passive cooling after participants performed intense outdoor exercise in warm weather (bias of T_{GI} compared with T_{REC} = –0.19°C)[7] or in a climatic chamber (bias of T_{GI} compared with T_{REC} = 0.13°C).[17] The reliability and validity of T_{GI} during passive cooling are especially important because postexercise measurements are used to determine when to safely discharge an athlete after exercise.

During exercise, the metabolic heat produced by the working muscles must be dissipated to mitigate the rise in body temperature and prevent extreme levels of hyperthermia. Heat dissipation relies on the thermal gradients from the core to the skin and then from the skin to the environment, where heat is lost via evaporation, convection, and radiation.[19,20] Heat transfer from the core to the skin or the skin to the environment is directly proportional to the temperature difference between the 2 locations, allowing for greater heat transfer as the temperature gradient increases. During exercise in hot environmental conditions, heat losses via convection and radiation are minimized (ie, the thermal gradient between the skin and the environment is minimized), thus requiring the body to rely on sweat evaporation from the skin as the primary mode of heat dissipation.[20]

It is not uncommon for individuals finishing a road race to have body temperatures of 39°C to 40°C, especially when the ambient temperature and relative humidity are high. In hot environmental conditions, the gradient from the skin to the environment for dissipating heat from the body is minimized, which may limit an individual's ability to lower core body temperature. However, limited research has examined the degree of passive cooling in hot environmental conditions when body temperature is elevated to a nonpathologic level of hyperthermia.

Therefore, the primary aim of our study was to investigate changes in the T_{GI} and T_{REC} of runners immediately after completing an 11.3-km road race in warm weather. The competitive context of a road race and expected thermal environmental strain might provide additional evidence to support the use of the T_{GI} pill in the athletic setting. We hypothesized that T_{GI} would be similar to T_{REC} within an acceptable range and would, thus, measure similar cooling rates during passive rest after exercising in warm weather. Our secondary aim was to investigate the passive cooling rate in individuals with elevated body temperatures after they completed a warm-weather road race. We expected that individuals with higher initial body temperatures would have faster cooling rates because they had a greater potential for heat loss.

METHODS

Participants

A total of 32 runners who registered for the 2014 Falmouth Road Race were recruited to participate in this study. Participants were included if they were between 20 and 60 years old on race day, their self-predicted finish time was under 60 minutes, and they had no history of EHS within the previous 3 years or any obstructive gastrointestinal tract disorder. Participants were briefed on the study protocols, which included the benefits and risks of involvement, and then signed an informed consent form that had been approved by the Institutional Review Board at the University of Connecticut, which also approved the study.

Procedures

The day before the race, each participant met with the researchers to obtain a T_{GI} pill (CorTemp, HQ Inc, Palmetto, FL) that he or she was to ingest 6 to 8 hours before the start of the race in order to provide an accurate measure of T_{GI} on race day. Participants were also instructed in the proper use of the global positioning satellite-enabled watch with heart-rate (HR)–monitoring capabilities (Run Trainer 1.0; Timex Group USA, Inc, Middlebury, CT) that they were to wear during the race to track time, distance, HR, and pace.

On the morning of the race, participants met the researchers before going to the starting line. Participants provided urine samples for hydration assessment, which was conducted using urine specific gravity (USG; model A300CL, Atago Inc, Tokyo, Japan), and were weighed to the nearest 0.1 kg (model BWB-800; Tanita Corporation, Tokyo, Japan) with minimal clothing after removing their shoes and running shirts. Duplicate (and triplicate when necessary) body fat measurements were taken using skinfold calipers (Lange skinfold calipers; Beta Technology, Santa Cruz, CA) at the chest, abdomen, and thigh for men and at the triceps, suprailiac area, and anterior thigh for women.[21,22] Participants then donned the watch and HR strap and were again instructed on the proper use of the watch. Presence of the T_{GI} pill was confirmed using a handheld device.

Immediately upon finishing the race, participants returned to the research tent for postrace measurements. The T_{GI} was measured immediately upon arrival. Participants were then weighed wearing minimal clothing, and they provided postrace urine samples for the calculation of body mass loss and hydration status. Next, participants entered a private bathroom and inserted a rectal thermistor (DataTherm II; RG Medical Diagnostics, Wixom, MI) 10 cm past the anal sphincter and then returned to the research tent to begin passive rest. During passive rest, T_{GI}, T_{REC}, and HR were measured every 2 minutes for a total of 20 minutes. Participants sat on chairs in an upright position under a tent with natural airflow. The ambient temperature, relative humidity, and heat index were 25.3°C ± 0.6°C, 74.1% ± 4.1%, and 26.2°C ± 0.9°C, respectively, on race day.

Data Analysis

We performed the statistical analysis using SPSS (version 21; IBM Corporation, Armonk, NY). All data are reported

Table. Participant Demographic Characteristics on Race Day

		Mean ± SD					
						Urine Specific Gravity	
Group	n	Age, y	Body Fat, %	Body Mass, kg	Body Mass Loss, %	Prerace	Postrace
Men	15	41 ± 11	19.4 ± 4.7	77.2 ± 8.0	1.3 ± 0.6	1.014 ± 0.007	1.010 ± 0.007
Women	15	37 ± 10	18.9 ± 5.5	59.3 ± 7.1	1.1 ± 0.9	1.014 ± 0.008	1.007 ± 0.008
Combined	30	39 ± 11	19.2 ± 5.0	68.3 ± 11.7	1.2 ± 0.8	1.014 ± 0.08	1.009 ± 0.007

as mean ± SD. Finish times for participants by sex were compared using a 2-tailed, 1-sample *t* test. A condition × time repeated-measures analysis of variance was calculated to examine the differences in T_{GI} and T_{REC} during passive rest. If an interaction was significant, Tukey post hoc analysis was conducted with the α level set a priori to .05. Separate correlation analyses were used to examine the relationship between postrace T_{GI} and cooling rates during passive rest. Mean bias and LOA were calculated using Bland-Altman analysis to examine the validity of T_{GI} and T_{REC}.[23] We also measured agreement using the Pearson product moment correlation coefficient, coefficient of variation, and intraclass correlation coefficient. The T_{GI} pill measurement was considered invalid if the mean bias exceeded ±0.27°C.[8]

RESULTS

Data for 2 participants were not included in the final data analysis because they passed the T_{GI} pill before the prerace data collection time point. Demographics of those who completed the study are shown in the Table. Average finish time was 55.98 ± 6.63 minutes, and there was no difference between men (54.62 ± 7.51 minutes) and women (57.35 ± 5.54 minutes) (P = .242). Average HR was 172 ± 11 beats per minute (bpm), and there was no difference between men (173 ± 12 bpm) and women (171 ± 10 bpm) (P = .610).

Postrace T_{GI}

Immediately upon completion of the race, arrival T_{GI} averaged 39.60°C ± 0.76°C among participants. The average T_{GI} for male and female runners was 39.53°C ± 0.72°C (range, 37.65°C–40.65°C) and 39.67°C ± 0.82°C (range, 38.51°C–41.06°C), respectively (P = .454). Nine runners completed the race with T_{GI} ≥40°C (5 men, 4 women). No central nervous system (CNS) dysfunction or EHS-related symptoms were reported during the postrace passive rest period.

Passive Rest Body Temperature

During passive rest, maximal mean body temperature was observed at minute 0 (T_{GI} = 38.80°C ± 0.94°C, T_{REC} = 39.02°C ± 0.92°C). The changes in T_{REC} and T_{GI} and the Δ change of HR during passive rest are depicted in Figure 1. The repeated-measures analysis of variance revealed a significant main effect of time; body temperature was reduced over the course of passive rest (F = 48.43, P < .001). Further analysis, however, revealed no differences between T_{REC} and T_{GI} at any point during passive rest (F = 0.749, P = .542). The cooling rates observed between T_{GI} (0.046 ± 0.031°C·min^{-1}) and T_{REC} (0.060 ± 0.036°C·min^{-1}) were different (mean difference [95% confidence interval] = 0.01 [0.00, 0.02]; P = .037) during passive rest. Despite the difference in absolute cooling rates during the passive rest period, changes in T_{GI} (1.16°C ± 0.18°C) and T_{REC} (1.23°C ± 0.16°C) were not different during passive rest (mean difference [95% confidence interval] = 0.07 [–0.13, 0.18]; P = .706). Runners finishing the race with a higher arrival T_{GI} had increased cooling rates with respect to the T_{GI} cooling rate (R = 0.682, P < .001) and the T_{REC} cooling rate (R = 0.541, P = .001; Figure 2). During the 20-minute passive rest, participant HR declined by 18 ± 9 bpm (Figure 1).

Validity of Temperature Devices

The mean bias of T_{GI} when compared to T_{REC} was –0.06°C ± 0.56°C with 95% LOA of ±1.09°C. The Pearson product moment correlation coefficient, coefficient of variation, and intraclass correlation coefficient between T_{GI} and T_{REC} were r = 0.782, 1.12% ± 0.91%, and 0.876, respectively. The Bland-Altman plot depicting the differences between T_{GI} and T_{REC} is shown in Figure 3.

DISCUSSION

The purpose of our study was to compare T_{GI} and T_{REC} during passive rest after participants completed an 11.3-km road race in warm weather. Previous authors[7,8] have examined the validity of various temperature-assessment devices against the criterion of rectal temperature but not in a competitive athletic setting. Our results support our hypothesis that T_{GI} is a valid measure of body temperature in individuals with hyperthermia competing in a warm-weather road race. We believe this is the first study to closely examine the differences between T_{GI} and T_{REC} during passive rest immediately after competitive exercise in warm weather.

The mean bias between T_{GI} and T_{REC} measurements during outdoor exercise was lower (–0.06°C ± 0.56°C) than that shown by earlier investigators (range, –0.15°C to –0.29°C).[7,16,24] Field studies by Casa et al[7] and Ganio et al[8] demonstrated differences of 0.19°C and 0.14°C between T_{REC} and T_{GI}, respectively. The larger differences between the measurements may be attributed to the timing of ingestion of the temperature pill: 6 to 8 hours before prerace data collection in the current study versus 3 hours in the study by Casa et al.[7] The timing of ingestion may influence the proximity of the temperature pill to the rectal thermistor, thus producing greater variance in the measure. For example, Savoie et al[18] observed a greater difference between T_{REC} and T_{GI} measurements when water was ingested, which would occur if the temperature pill was located adjacent to the stomach in the upper intestine. However, this can be mitigated if the pill is taken well before the temperature assessment. Examining the differ-

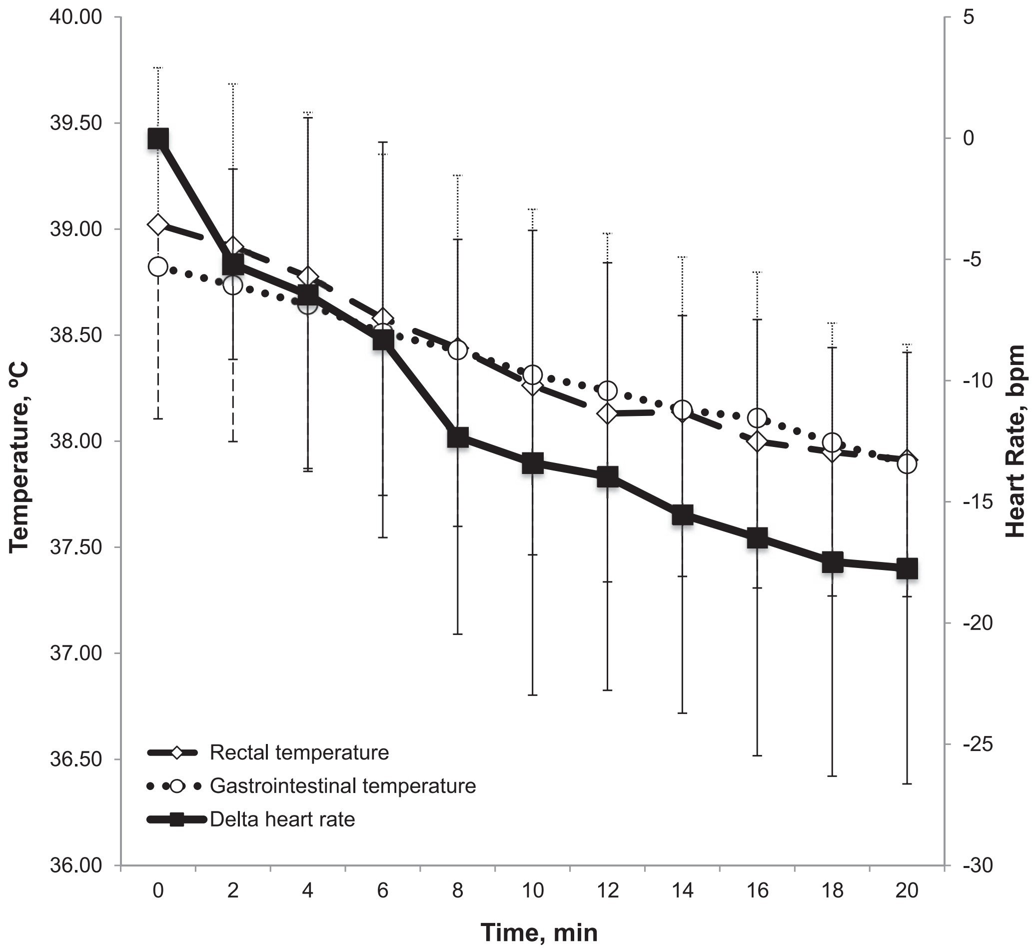

Figure 1. Changes in rectal temperature and gastrointestinal temperature and the Δ change in heart rate observed during the 20-minute postrace passive rest.

ences between T_{REC} and T_{GI} measurements in a controlled laboratory setting to minimize the variability due to environmental conditions, Ganio et al[8] found a mean bias of –0.02°C. Our results more closely match those of Ganio et al[8] than those of previous studies in field settings, which further supports the use of T_{GI} versus T_{REC} as a valid measure of body temperature.

Overall, cooling rates based on T_{GI} and T_{REC} measurements were statistically different during passive rest. However, the mean difference was 0.01°C, which we believe is negligible and could be attributed to the variability between devices. One explanation is the difference between T_{GI} and T_{REC} at time point 0 of passive rest: 38.92°C ± 0.94°C and 39.02°C ± 0.92°C, respectively. This subtle difference caused the variation in absolute cooling rates, as the difference between T_{GI} and T_{REC} measures at the end of passive rest was negligible: 37.89°C ± 0.56°C and 37.91°C ± 0.63°C, respectively.

Unique to our immediate postrace measures, we found that 9 participants finished the race with a T_{GI} >40°C without displaying CNS dysfunction. Diagnostic criteria for EHS include (1) body temperature, using a valid measure and (2) obvious CNS dysfunction.[25,26] Our results support the need for both diagnostic criteria to be met before EHS is diagnosed. In the event of EHS, prompt whole-body cooling using cold-water immersion is the gold standard of treatment to ensure survival.[25,27] It is evident from our findings that some individuals are able to complete exercise with body temperatures >40°C without evidence of CNS dysfunction, and they continue to efficiently thermoregulate while resting passively. From a clinical standpoint, we reemphasize that passive-cooling rates similar to those we observed are sufficient for athletes showing no clinical signs or symptoms of EHS. The occurrence of EHS warrants immediate and aggressive cooling, which is not provided to a patient by passive cooling.

Given the environmental conditions at the race (ambient temperature = 25.3°C ± 0.6°C, relative humidity = 74.1% ± 4.1%), it is unlikely that increased body temperature would be a favorable factor in convective heat loss because the heat gradient between the environment and skin temperature would be minimized, thus reducing the convective heat-loss gradient.[28] Yet our results provide evidence that those who completed the race with higher body temperatures exhibited greater cooling rates during passive rest. Although we are unaware of any other authors who have shown this specific effect, the ability of individuals to effectively thermoregulate and exhibit higher passive-cooling rates when body temperature is high may be due to the body's natural heat dissipation via sweat evaporation. Kenny et al[29] noted that skin blood flow and sweating were maintained with elevated body temperatures,

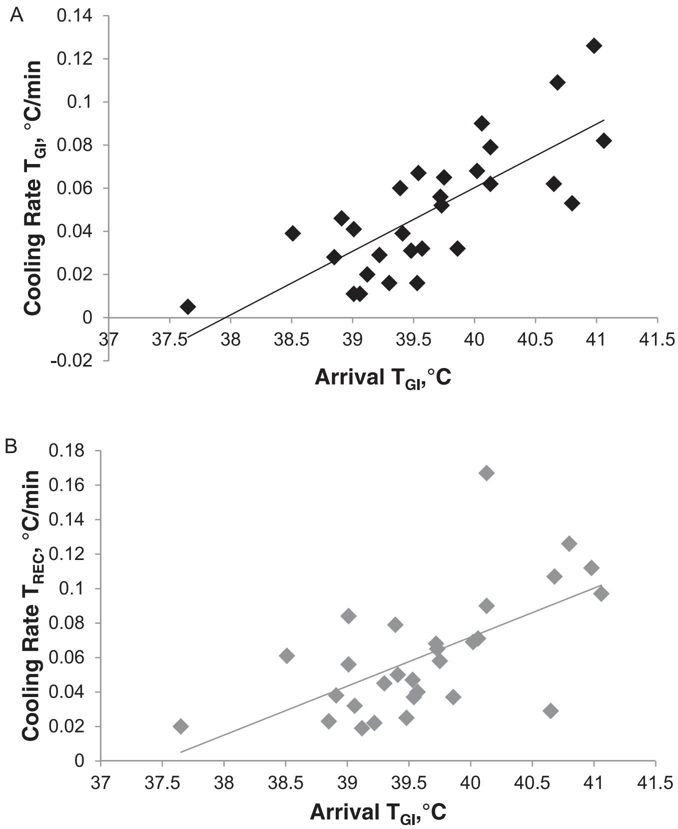

Figure 2. Linear correlation plot between the arrival gastrointestinal temperature (T_{GI}) and the A, T_{GI} cooling rate (*R* = 0.682, *P* < .001) and B, Rectal temperature (T_{REC}) cooling rate (*R* = 0.541, *P* = .001).

which may allow heat dissipation to be maintained through evaporation of sweat.

Lastly, when it is feasible to ingest the T_{GI} pill before physical activity, T_{GI} is a viable option for monitoring body temperature in athletes with exercise-induced hyperthermia. Recently, field application of a T_{GI} pill was implemented to monitor the T_{GI} temperature of an EHS survivor still acclimatizing to the heat in the return-to-play protocol.[15] More study on the timing of pill ingestion is warranted to further validate the safety of administering the T_{GI} pill in a field setting. Future authors should also investigate the use of T_{GI} during cold-water immersion for determining when to remove the patient from the tub during acute care for EHS.

Limitations

Because of the possibility that the rectal thermistor could fall out during the run, we had our participants insert the rectal thermistor after completing the race. This did not afford us the opportunity to compare immediate postrace measures of T_{GI} and T_{REC}. Also, given that participants had to insert the rectal thermistor after completing the race, the time it took to insert the thermistor was highly variable. This could have affected the temperature measurements and overall cooling rates that we observed, as body temperature at the start of passive rest was not the maximum body temperature attained upon completion of the race.

In addition, we did not control for water intake during the passive rest. This could have influenced overall cooling by creating a heat sink in the gut that might have enhanced the ability to cool.[30] We are also unaware of any potential influence of the cold fluid on the measurement of T_{GI} when the pill is taken with enough time for it to pass into the small intestine before the fluid is ingested. Furthermore, large individual variations in transit time through the digestive tract could have influenced the exact location of the pill, which may have influenced the temperature measurement. Results from our laboratory have shown that it is possible for the T_{GI} pill to pass from the body in less than 4 hours or to remain in the stomach 12 hours after ingestion, representing large individual variations when the pill is taken orally. Because our participants ingested the pill 6 to 8 hours before the start of the race, we can assume that the pill was located in the lower intestine, which would not have been affected by the cold fluid in the gut.[31] Furthermore, we did not observe fluctuations in the T_{GI} measurements when participants drank water (0 to approximately 200 mL) ad libitum during the passive rest.

CONCLUSIONS

The purpose of our study was to investigate the validity of T_{GI} against the criterion measure of T_{REC} for measuring body temperature in individuals with hyperthermia who completed an 11.3-km road race in warm environmental conditions. We found that T_{GI} was a valid measurement of body temperature compared with T_{REC} when assessing passive rest after intense exercise in warm weather. Due to the constraints associated with T_{GI} (timing of pill ingestion, potential for the pill to malfunction or be passed), T_{REC} should remain the primary mode of temperature assessment

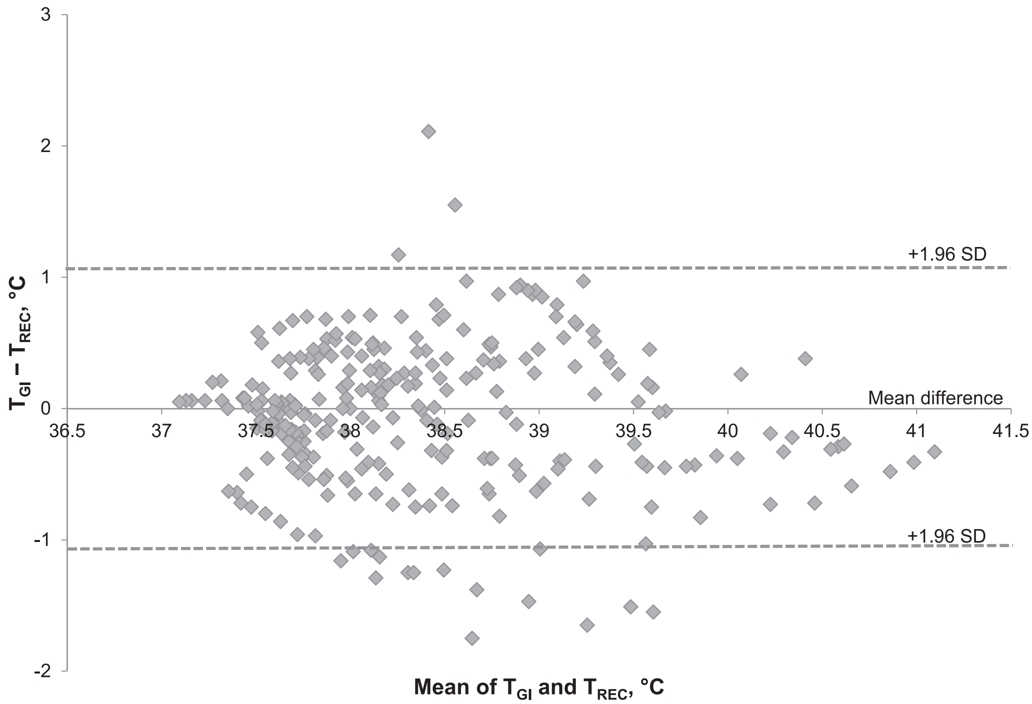

Figure 3. Bland-Altman plot depicting the differences between gastrointestinal temperature (T_{GI}) and rectal temperature (T_{REC}) observed during the 20-minute postrace passive rest.

when a clinician makes a medical decision to diagnose EHS.

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