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Original Article

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Application of the Bair Hugger™ core body temperature at wrist region with upper body warming blanket: a prospective observational study

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Background: Body temperature monitoring is essential during the perioperative period. However, core body temperature measurement requires invasive device that may cause complications. This study aimed to evaluate the accuracy of non-invasive Bair Hugger™ core body temperature monitoring system (BHTMS) at the wrist compared with esophageal temperature under general anesthesia.

Methods: Twenty adult patients of the American Society of Anesthesiologists physical status I or II were enrolled. BHTMS sensor was applied at wrist region. After tracheal intubation, an esophageal probe was inserted. Bair Hugger™ upper body warming blankets were used. Esophageal temperature (T_{eso}) and BHTMS at wrist (T_{wrist}) were recorded every 10 min.

Results: Total of 257 pairs of data sets were analyzed: T_{eso} and T_{wrist} had no statistically significant difference (P = 0.103). Median of T_{eso} and T_{wrist} were 36.5°C and 36.4°C. Bland-Altman analysis showed T_{eso} – T_{wrist} of 0.14°C ± 1.44. Subsequently, 99 pairs of 0–40 min data set were analyzed and showed significant difference at 0 and 10 min (P < 0.001) but no significant difference at 20, 30 and 40 min. Bland– Altman plot by times showed difference (T_{eso} - T_{wrist}) of 1.49°C ± 2.00, 0.82°C ± 1.30, 0.29°C ± 1.32, −0.03°C ± 0.84, and −0.12°C ± 0.82 at 0, 10, 20, 30 and 40 min respectively.

Conclusions: BHTMS at wrist area under the upper body warming blanket is a potential alternative other than esophageal temperature for monitoring body temperature after 30 min of anesthesia induction.

Keywords: Body temperature; Hypothermia; Intraoperative care; Intraoperative monitoring; Perioperative period; Thermometers.

INTRODUCTION

Body temperature monitoring during the perioperative period is essential because of the variability during surgery. Body temperature often decreases during surgery because of thermoregulation disruption due to general anesthesia and cold exposure to procedural surroundings [1-4]. Perioperative hypothermia may cause mild consequences such as patient's discomfort, shivering and severe complications such as increased bleeding [1] due to abnormal coagulopathy [2], higher risk of surgical site infection [3] and life-threatening arrhythmia [4]. Meanwhile, body temperature may increase soon after the induction of general anesthesia if malignant hyperthermia is triggered by exposure to volatile anesthetic agents or succinylcholine [5]. Immediate recognition and treatment should be started without delay in the occurrence of malignant hyperthermia [6]. Therefore, we should be able to monitor perioperative body temperature accurately.

Nevertheless, skin temperature may differ greatly from the actual body temperature; thus core body temperature must be measured to ensure accuracy [7]. Core body temperature can be obtained from the tympanic membrane, nasopharynx, esophagus, pulmonary artery, bladder and rectum. However, temperature measurements at these sites require using invasive placement of sensors.

Esophageal temperature is strongly associated with pulmonary artery temperature and is used as a basic temperature measurement method for intubated patients [8]. Esophageal probe insertion is usually considered to be a safe method; however, there is the possibility of complications such as esophageal bleeding, perforation, and arrhythmias [8]. Moreover, inserting esophageal probe is difficult when supraglottic airway is used.

To measure core body temperature in a non-invasive way, Fox and Solman [9] first invented the non-invasive zero-heat-flux thermometer in 1971. 3M developed a 3M™ Bair Hugger™ temperature monitoring instrument for use in clinical practice. It is a zero-heat-flux thermometer consisting of two thermistors, a thermal insulator and an electrical heater. A sensor is put on the forehead region and insulates the skin locally by heating. An area of isothermic tunnel is then created from the skin to the core body part such as the brain. At that point, the state of zero heat flux reflects the core body temperature [10-12]. Safety and usefulness of this method have already been reported. Previous studies have proved the reliability of this method through comparison with esophageal probe [10], nasopharyngeal probe [11], and pulmonary artery catheter [13]. The Bair Hugger™ temperature monitoring system (BHTMS) has some advantages, such as its accuracy, ease of use with disposable sensors, and non-invasiveness. However, the BHTMS may not be able to be applied to the forehead area owing to several reasons such as the field of surgery involving the head, skin problem at the attachment site, and interference of other monitoring probes on the forehead.

Therefore, instead of the forehead area, the BHTMS sensor is applied to another area of the body. According to Tachibana et al. [14] a relatively accurate temperature could be obtained even if the BHTMS sensor was attached to the neck. However, temperature obtained at the chest regions did not show accurate values. Considering the principle of zero-heat-flux thermometer, we hypothesized that core body temperature can be obtained from the wrist area using BHTMS. The wrist area has a radial artery running about 5 mm below the skin, has little influence by fatty tissues, and is easy to approach [15]. To date, no studies have focused on the use of BHTMS at the wrist region. Hence this study aimed to determine whether an accurate core body temperature can be obtained from the wrist region using BHTMS in patients under general anesthesia by comparing it with esophageal temperature.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of Chung-Ang University Hospital (registration no: 2112F-030-489) and it was registered at the Clinical Research Information Service clinical trials registry (KCT0007211) before patient recruitment. Written informed consent was obtained from each patient before surgery.

The study was conducted between March 2022 and August 2022. Patients of the American Society of Anesthesiologists physical status I or II who were planned to undergo orthopedic surgery under general anesthesia were included. Pediatric patients, pregnant patients, patients with esophageal lesions such as esophageal varix or stricture, abnormalities at the wrist region, and hematologic disease of bleeding tendency were excluded. We included patients with minimal risk of massive bleeding during surgery.

Before the induction of general anesthesia, the BHTMS sensor (3M™ Bair Hugger™ Temperature Monitoring Patient Sensor, 36000 and 3M™ Bair Hugger™ Temperature Monitoring System, 37000) was attached to the patient's wrist. The center of the sensor was placed at the radial artery pulsation site. Anesthesia was induced by propofol (1.5–2.0 mg/kg) and remifentanil (0.5 μg/kg), and tracheal intubation was performed 90 s after injecting 0.6–0.9 mg/kg rocuronium.

Maintenance of anesthesia was performed using air-oxygen-sevoflurane with FiO_2 0.5. Sevoflurane dosage was adjusted at 1.5–2.0 minimum alveolar concentration to maintain patient state index of 25–50 at the SEDLine monitor (SEDLine™, Masimo, CA). After the tracheal intubation, an esophageal probe (ETP1040, Ewha Biomedics) was inserted through the mouth with the insertion depth determined using the equation (depth [cm] = 0.228 × standing height [cm] – 0.194) to target the region of esophagus bounded by the left ventricle and aorta [16]. Temperature recording began after equilibration, which was defined as 0 min [T_0]. Patients were warmed appropriately at the upper body using a Bair Hugger™ forced-air warming unit (3M™ Bair Hugger™ Warming Unit Model 775, 3M) and Bair Hugger™ upper body warming blankets (3M™ Bair Hugger™ Warming Blanket Model 622, Multi-position, 3M), under high operating temperature (43°C). Warming blanket covered the whole upper body including the wrist area. The warming system was turned off when esophageal temperature (T_{eso}) reached over 37.3°C. T_{eso} and BHTMS at the wrist region (T_{wrist}) were recorded every 10 min until the end of the surgery. Before extubation, esophageal temperature probe and BHTMS sensor were removed. The operating room temperature was maintained at 20–24°C throughout the study period.

Our primary end point was comparison of consistency between T_{eso} and T_{wrist}. The secondary end points include the accuracy and correlation between T_{eso} and T_{wrist} by times at 0, 10, 20, 30, and 40 min (T_0, T_{10}, T_{20}, T_{30}, and T_{40}, respectively), and accuracy between T_{eso} and T_{wrist} after 30 min of anesthesia induction.

Statistical analysis

During the research planning, we performed a pilot study, collecting 132 pairs of data from 11 patients. After the pilot study, the sample size was calculated with G Power software (Ver. 3.1.9.7, Heinrich-Heine-Universität Düsseldorf) using a paired *t*-test. The mean difference was 0.15 and the standard deviation (SD) was 0.38. When calculated with an alpha value of 0.01 and power of 0.8, the sample size was 79. In the pilot study, the shortest duration of surgery was 40 min. It means 1 patient yielded a minimum of 5 data sets. Therefore, we divided 79 by 5 to calculate minimum number of participants. Then, considering 20% of drop out rate, 20 patients were decided as the total number of participants.

The distribution of parameters was evaluated for normality using the Kolmogorov-Smirnov test. Non-normally distributed data were compared using the Wilcoxon signed rank test and Spearman correlation and are expressed as median and interquartile range. Normally distributed data were compared using the paired t-test and Pearson correlation and are expressed as mean and SD. For the comparison of T_{eso} and T_{wrist} data by times, Bonferroni correction was performed. P value < 0.01 was considered significant. Bland–Altman plots were also used to evaluate the limits of agreement and were expressed as mean bias (T_{eso} – T_{wrist}) ± 2SD. All statistical analyses were performed using dBSTAT for Windows (Ver. 5.0, dBSTAT).

RESULTS

A total 258 pairs of data were collected from 20 patients. Table 1 summarizes the demographic data and duration of anesthesia. In one case, a pair of data at 0 min was deleted because of T_{wrist} missing data due to an electronical problem. Therefore, 257 pairs of data were analyzed using the Wilcoxon signed rank test and Spearman correlation. Median (1Q, 3Q) of T_{eso} and T_{wrist} were 36.5°C (35.95°C, 36.8°C) and 36.4°C (35.8°C, 36.8°C), respectively. T_{eso} and T_{wrist} had no statistically significant difference (P = 0.103) (Fig. 1). The Spearman's correlation coefficient was 0.567 (Fig. 2).

Each patient had a different length of anesthesia time according to the type of surgery. Table 2 summarizes the types of surgery. The shortest surgery duration was 40 min. Overall, 99 pairs of data were organized and analyzed according to the measurement time intervals (0, 10, 20, 30 and 40 min). The paired *t*-test and Pearson correlation were performed, and Table 3 summarizes the result of paired *t*-test. A significant difference was observed at T_0, T_{10} and T_{20} whereas no significant difference was observed at T_{30} and T_{40}. Fig. 3 shows the Pearson's correlation coefficients of T_{eso} and T_{wrist} by times, which were 0.262, 0.606, 0.679, 0.746, and 0.718 at T_0, T_{10}, T_{20}, T_{30}, and T_{40} respectively.

A Bland–Altman analysis was also performed. For the primary outcome, mean difference (T_{eso} – T_{wrist}) of 257 pairs of data was 0.14°C with a 2SD of ± 1.44 (Fig. 4). For the second-

Table 1. Demographic Data

Variable	Value (n = 20)
Sex (M/F)	11/9
Age (yr)	47.8 ± 19.3
Height (cm)	165.8 ± 8.8
Weight (kg)	69.9 ± 12.8
BMI (kg/m^2)	25.3 ± 3.2
Anesthesia time (min)	129 ± 52.7
ASA-PS (I/II)	10/10

Values are presented as number only or mean ± SD. BMI: body mass index, ASA PS: American Society of Anesthesiologists physical status.

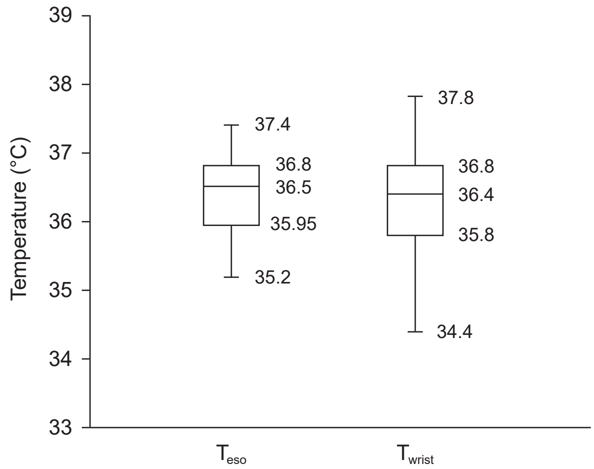

Fig. 1. Comparison of T_{eso} and T_{wrist}. Wilcoxon signed rank test was performed, and no statistical difference was observed (P = 0.103). T_{eso}: esophageal temperature, T_{wrist}: temperature recorded using the Bair Hugger™ core body temperature monitoring system at the wrist.

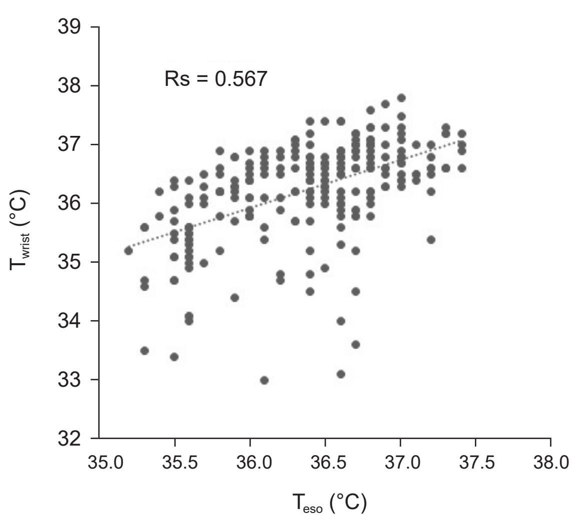

Fig. 2. Spearman correlation between T_{eso} and T_{wrist}. T_{eso}: esophageal temperature, T_{wrist}: temperature recorded using the Bair Hugger™ core body temperature monitoring system at the wrist, Rs: Spearman correlation coefficient.

Table 2. Types of Surgery

Arthroscopic surgery of knee or shoulder	3
Total knee replacement	4
Metal removal of ankle or knee or clavicle	6
ORIF of ankle or hand or humerus	3
Ligament reconstruction of elbow or knee	2
Ulnar osteotomy	2
Total	20

Values are presented as number only. ORIF: open reduction and internal fixation.

Table 3. Comparison of T_{eso} and T_{wrist} (°C) by Times

	T_{eso}	T_{wrist}	P value
0 min	36.31 ± 0.54	34.82 ± 0.99	< 0.001
10 min	36.18 ± 0.53	35.36 ± 0.82	< 0.001
20 min	36.18 ± 0.50	35.89 ± 0.88	0.063
30 min	36.21 ± 0.53	36.24 ± 0.62	0.751
40 min	36.25 ± 0.52	36.38 ± 0.56	0.203

Values are presented as mean ± SD. T_{eso}: esophageal temperature, T_{wrist}: temperature recorded using the Bair Hugger™ core body temperature monitoring system at the wrist. The two groups were compared using the paired *t*-test. Bonferroni correction was performed on the data. P value < 0.01 was considered significant.

ary outcome, the Bland–Altman plot was constructed for T_{eso} and T_{wrist} by times. The mean bias (T_{eso} – T_{wrist}) ± 2SD were 1.49°C ± 2.00, 0.82°C ± 1.30, 0.29°C ± 1.32, –0.03°C ± 0.84, –0.12°C ± 0.82 at T_0, T_{10}, T_{20}, T_{30}, and T_{40}, respectively (Fig. 5).

DISCUSSION

This study aimed to determine whether an accurate core body temperature can be obtained from the wrist region using BHTMS in patients under general anesthesia by comparing it with esophageal temperature. We compared T_{eso} and T_{wrist} as the primary outcome. Wilcoxon signed-rank test showed that T_{eso} and T_{wrist} had no significant difference. Spearman correlation showed a moderate positive correlation. However, the Bland–Altman plot of T_{eso} and T_{wrist} showed a mean bias (T_{eso} - T_{wrist}) ± 2SD of 0.14 ± 1.44°C.

Boisson et al. [10] compared the temperature recorded using BHTMS at the forehead with esophageal temperature, and the result showed mean bias and limit of agreement (LOA) of 0.1 ± 0.5°C. Iden et al. [11] compared the temperature recorded using this method with nasopharyngeal temperature, showing almost identical results (0.07 ± 0.42°C). Eshraghi et al. [13] compared the temperature recorded using BHTMS with pulmonary artery temperature and found a result of –0.23 ± 0.82°C. Also, Tachibana et al. [14] compared the temperature recorded using BHTMS at the neck with esophageal temperature, showing a result of 0.05 ± 0.35°C. Tachibana et al. [14] considered a mean value of the difference (bias) < 0.4°C and 2SD < ± 1.0°C as appropriate standard for comparing the two methods. In this study, we compared T_{eso} and T_{wrist} by considering the same standard as Tachibana's study and the result of mean bias (T_{eso} - T_{wrist}) ± 2SD of 0.14 ± 1.44°C did not meet the agreed standard.

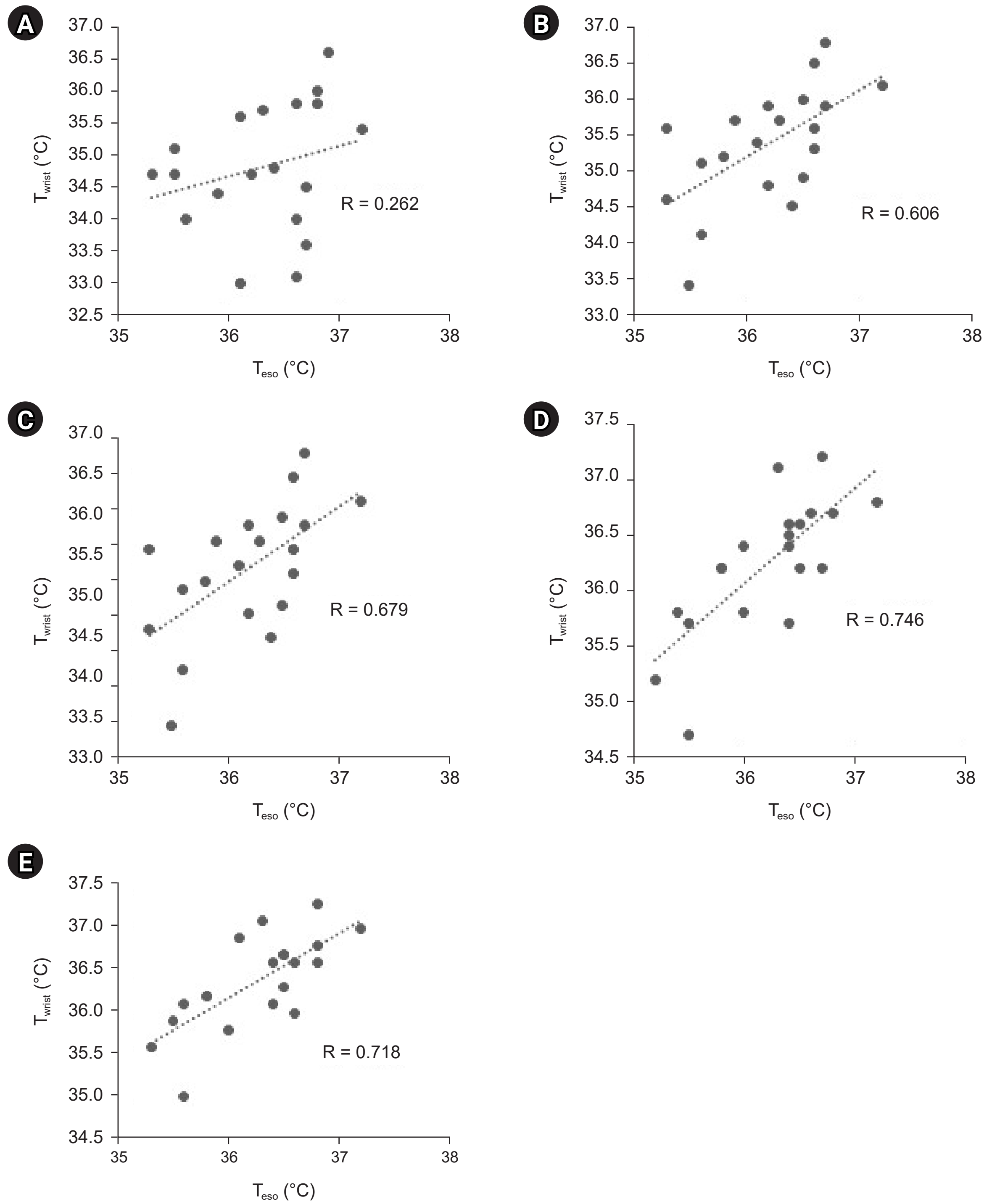

Fig. 3. Pearson correlation between T_{eso} and T_{wrist} by times. T_{eso} and T_{wrist} were recorded at 0 min (A), 10 min (B), 20 min (C), 30 min (D) and 40 min (E). T_{eso}: esophageal temperature, T_{wrist}: temperature recorded using the Bair Hugger™ core body temperature monitoring system at the wrist, R: Pearson correlation coefficient.

For the secondary outcomes, the T_0, T_{10}, T_{20}, T_{30}, and T_{40} data were analyzed. T_0 and T_{10} showed significant differences in the paired t-test, whereas T_{20}, T_{30}, and T_{40} showed no significant difference. Additionally, there was a positive correlation between T_{eso} and T_{wrist} at T_0–T_{40}, although the T_0 showed a weak correlation. However, T_{10}, T_{20}, T_{30}, and T_{40} showed moderate to strong correlations. From the Bland–Altman analysis result, we noticed that only T_{30} and T_{40} could

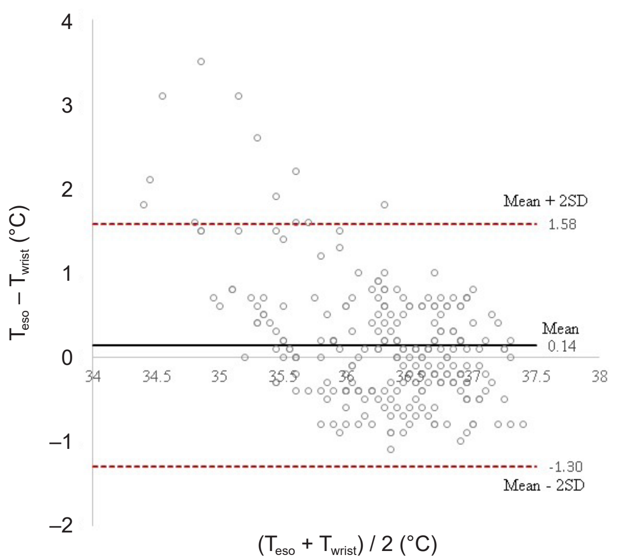

Fig. 4. Bland-Altman plot of T_{eso} and T_{wrist}. T_{eso}: esophageal temperature, T_{wrist}: temperature recorded using the Bair Hugger™ core body temperature monitoring system at the wrist, SD: standard deviation.

be accepted as reliable, which met the earlier LOA standard [14]. For further analysis, we also performed Bland-Altman analysis with data collected from 30 min to the end of the surgery. It showed a mean bias (T_{eso} – T_{wrist}) ± 2SD of 0.08 ± 0.96°C, which met the agreed standard. Considering these results, temperature measurement using the BHTMS at the wrist is relatively accurate and equivalent to the esophageal temperature at least 30 min after the first temperature measurement.

In this study, at T_0, 10 of 20 patients showed immediate close approximation between T_{eso} and T_{wrist} ≤ ± 1.0°C. However, the remaining half of patients showed a wide difference between T_{eso} and T_{wrist}, up to 3.1°C, and the wide difference decreased progressively. The exact mechanism of the close approximation of T_{wrist} to T_{eso} after 30 min needs to be explicit. One reason, we assume, is the redistribution of body heat. Before the induction of general anesthesia, the peripheral compartment distant from the heart, such as the wrist region, typically shows a 2–4°C lower temperature than the core body temperature. This is the normal core-to-peripheral temperature gradient. General anesthesia is known to reduce vasoconstriction and cause peripheral vasodilation, which leads to perioperative hypothermia. The following redistribution increases the temperature of the peripheral region [17]. Furthermore, we assumed that the other reason is the direct heating effect of the upper body warming blanket. When we turned off the warming system owing to concern of hyperthermia, we could observe a wider difference between T_{eso} and T_{wrist}. Therefore, we believed that the upper body warming blanket has a direct heating effect. The time interval for the calibration of the BHTMS sensor and the time interval until the application of a warming blanket is another factor considered in the direct heating effect. Considering the calibration time, we applied the BHTMS sensor before intubation. Calibration was done within 5 min in every patient before placing the esophageal temperature probe. A warming blanket was applied after intubation or after positioning the patients for the operation. The time interval was not correctly measured during the study; however, it might have been up to 15 min.

Our study had several limitations. First, we monitored and analyzed a esophageal temperature range of 35.2–37.2°C in patients undergoing orthopedic surgeries. Therefore, we could not assure that BHTMS would correctly measure hyperthermia or hypothermia out of that range or in other surgery types. Second, for the secondary outcome, we did not compare the temperature by times after 40 min because the surgery time length differed in every patient. Thus, we could not perform comparisons of data by times after 40 min. Third, we did not include patients who did not use the warming system in the study because of the potential ethical issues. Also, we did not use warming system other than the upper body warming blanket. Further study using warming system other than the upper body warming blanket is needed. Fourth, we did not measure the BHTMS temperature at the forehead region and the peripheral skin temperature for comparison. Further studies comparing temperatures recorded using the BHTMS at the forehead, wrist, and peripheral skin temperature is needed. Fifth, the peripheral circulation of each patient was not evaluated although it might be concerned whether the location of radial artery was temperature of the fluid were not evaluated. However, considering the result of the secondary outcome, under the Bair Hugger™ upper body warming blankets, the influence of fluid after 30 min could be considered minimal.

Limitations stated above may lower the strength of this study. However, this study has meaningful number of participants and well documented methodology to be replicated. Also, Ethical guidelines were followed and potential threat of hypothermia or hyperthermia was prevented. Further studies should be proceeded with larger number of participants for longer duration of time, overall control of the potential

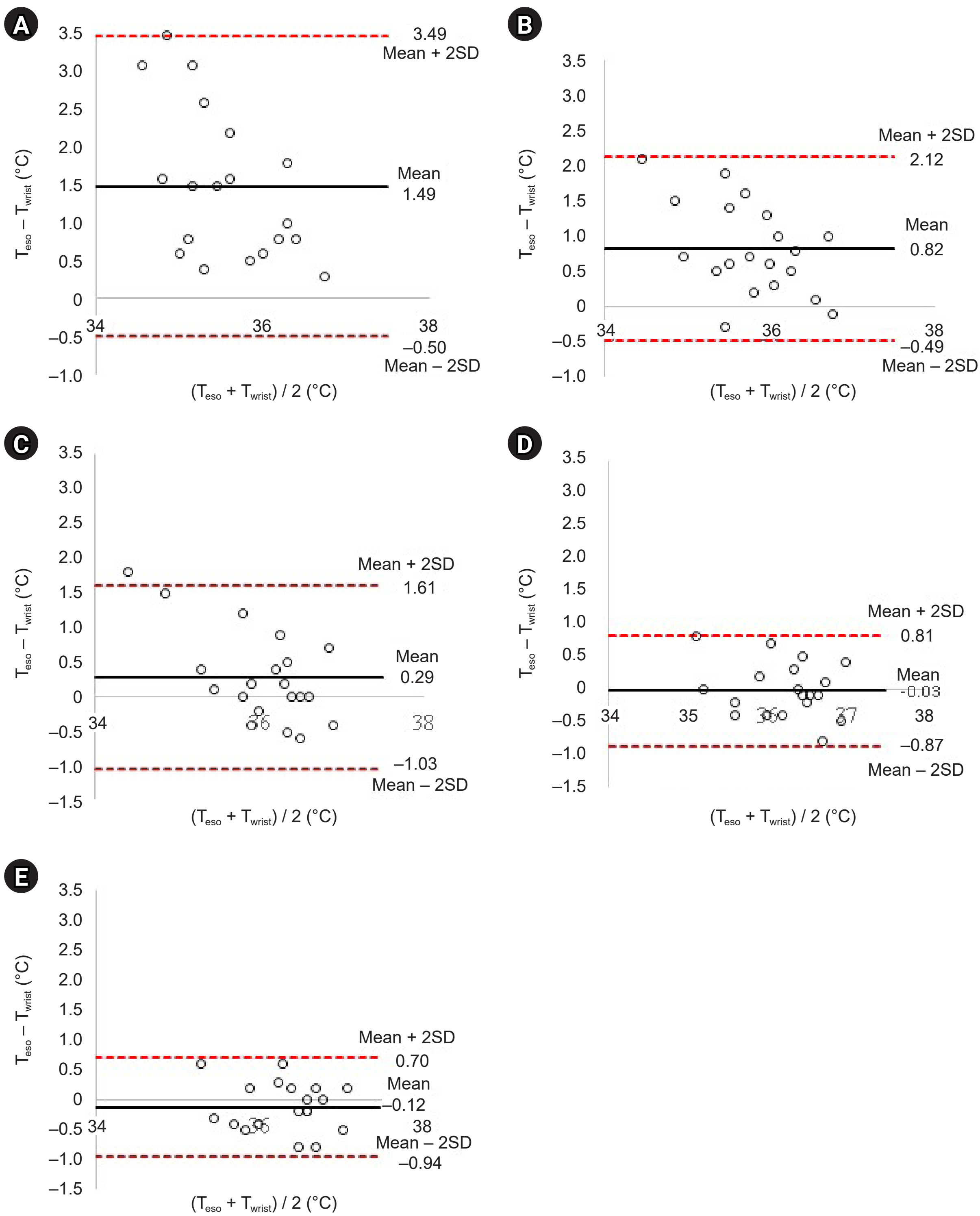

Fig. 5. Bland-Altman plots of T_{eso} and T_{wrist} at 0 min (A), 10 min (B), 20 min (C), 30 min (D), and 40 min (E). T_{eso}: esophageal temperature, T_{wrist}: temperature recorded using the Bair Hugger™ core body temperature monitoring system at the wrist, SD: standard deviation.

variables that may affect body temperature, and comparison with other temperature sites. In this study, results were inconclusive about the accuracy of BHTMS at wrist area. Even though, this study has significance for the suggestion of another possible alternative method for monitoring body temperature.

In conclusion, the accuracy of BHTMS at wrist area under upper body warming blanket is comparable to that of esophageal temperature after 30 min of anesthesia induction. Therefore, BHTMS may be another possible alternative method for monitoring body temperature after 30 min of anesthesia induction.

FUNDING

None.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

Writing - original draft: Kyung Seo Oh. Writing - review & editing: Kyung Seo Oh, Young-Cheol Woo. Conceptualization: Young-Cheol Woo. Methodology: Young-Cheol Woo. Project administration: Kyung Seo Oh. Investigation: Kyung Seo Oh. Supervision: Yong-Hee Park, Chongwha Baek, Young-Cheol Woo.

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