Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Efficacy of Preoperative Warming with Wireless Temperature Monitoring in Laparoscopic Colorectal Cancer Resection: A Randomized Controlled Trial

Xiangying Gao
First Affiliated Hospital of Wenzhou Medical University
wenwen Du
First Affiliated Hospital of Wenzhou Medical University
Yanyan Li
Gansu Provincial Hospital
Xiuxiao Zhu
First Affiliated Hospital of Wenzhou Medical University
Xiujie Wu
Zhejiang Taizhou Hospital
Sunrui Yu
First Affiliated Hospital of Wenzhou Medical University
Junlu Wang
First Affiliated Hospital of Wenzhou Medical University
Qinxue Dai
653091408@qq.com

First Affiliated Hospital of Wenzhou Medical University

Research Article

Keywords: Radical colorectal cancer surgery, Perioperative hypothermia, Pre-warming, Wireless temperature sensor.

Posted Date: July 9th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9883076/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background:

Perioperative hypothermia remains a common surgical complication, with reported incidence rates of 50%–70% when active warming is inadequate. Laparoscopic procedures, despite being minimally invasive, may increase hypothermia risk due to factors such as pneumoperitoneum. While continuous temperature monitoring is recommended, invasive methods are unsuitable for conscious patients, and most studies rely on static measurements that fail to capture dynamic core temperature changes. Evidence indicates that preoperative warming can reduce heat redistribution and accelerate recovery. To investigate this further, this study employed the wireless iThermonitor® for continuous monitoring combined with preoperative warming, aiming to provide new insights into hypothermia prevention.

Methods:

This single-center, prospective, randomized controlled trial enrolled 180 patients scheduled for elective laparoscopic radical colorectal cancer surgery. Participants were randomly allocated to either a pre-warming group (P group) or a routine warming group (C group), with 90 patients in each group.

Results:

The incidence of perioperative hypothermia was significantly lower in the P group (33.3%) than in the C group (76.6%) ($P < 0.001$). Furthermore, core body temperatures recorded at most perioperative time points were significantly higher in the P group than in the C group ($P < 0.05$), with the minimum temperature also significantly higher in the P group ($P < 0.001$). Among patients who developed hypothermia, the time from anesthesia induction to hypothermia onset was significantly longer in the P group ($P < 0.001$), while the duration of hypothermia was significantly shorter ($P = 0.012$). Except for delayed emergence and post-anesthesia care unit (PACU) length of stay—which did not differ significantly between groups—all other postoperative outcomes were significantly better in the P group than in the C group.

Conclusion:

Under wireless temperature monitoring, 30 minutes of preoperative pre-warming effectively reduced both the incidence and severity of perioperative hypothermia in patients undergoing laparoscopic radical colorectal cancer surgery. Preoperative pre-warming also reduced hypothermia-related complications and promoted rapid postoperative recovery.

Trial registration:

ChiCTR2600124213 Date: May 8, 2026 Retrospectively registered.

Key Points

1. Preoperative forced-air pre-warming (30 min) halved hypothermia incidence (33.3% vs 76.6%) in laparoscopic colorectal cancer surgery.
2. Continuous wireless temperature monitoring (iThermonitor®) revealed later-onset & shorter hypothermia in pre-warmed patients.
3. Pre-warming improved recovery (shorter extubation, first flatus) & reduced complications (shivering, PONV) and hospital costs.

1. Introduction

Body temperature is one of the five vital signs of the human body. Thus, maintaining a constant body temperature is essential for normal metabolism and physiological activities, and serves as a critical foundation for preserving bodily functions [1]. In healthy individuals, body temperature remains stable through a dynamic balance of heat production and dissipation. In recent years, with the widespread adoption of the Enhanced Recovery After Surgery (ERAS) concept in clinical practice, perioperative temperature monitoring and management has become a key component of ERAS clinical pathways [2, 3]. Core body temperature refers to the temperature of the thoracic and abdominal cavities as well as the central nervous system. Hypothermia is defined as a core temperature below 36°C. Inadvertent Perioperative Hypothermia (IPH) refers to an unplanned and harmful drop in core temperature below 36°C that occurs at any time during the perioperative period, excluding therapeutic or intentional hypothermia [4–6].

Hypothermia is one of the most common perioperative complications, with an incidence ranging from 50% to 90% [7]. It occurs even more frequently in pediatric and elderly surgical patients[8, 9]. Colorectal cancer is among the most common malignant tumors of the digestive system, ranking third globally in both incidence and mortality [10]. Laparoscopic radical colorectal cancer surgery is currently the most widely used surgical approach for colorectal cancer [11, 12]. Studies indicate that the incidence of IPH in such procedures can reach 74% [13]. Perioperative hypothermia is closely associated with various complications, including surgical site infection (SSI), coagulation dysfunction, delayed metabolism of anesthetic agents, and increased risk of cardiovascular events. Additionally, it may lead to prolonged mechanical ventilation, higher rates of pressure injuries, increased shivering, reduced thermal comfort, and extended stays in the Post-Anesthesia Care Unit (PACU), Intensive Care Unit (ICU), and overall hospitalization [14, 15].

To prevent perioperative hypothermia, commonly used clinical warming measures include passive insulation, active warming, heated irrigation fluids, maintaining operating room temperature above 21°C, and pharmacological interventions [5, 7, 16–20]. In recent years, multiple studies have demonstrated that

forced-air warming blankets are the most common and effective method of active warming in clinical practice [21–23]. Guidelines recommend that temperature monitoring for surgical patients should be dynamic, continuous, and cover the entire perioperative course. However, invasive monitoring is not suitable for awake patients and does not allow for full intraoperative monitoring [5, 24]. Moreover, most existing research on perioperative hypothermia relies on single-time-point measurements or averaged values from multiple measurements, overlooking the dynamic nature of temperature changes [21]. The wireless temperature sensor iThermonitor®, as a wearable non-invasive continuous monitoring device, not only enables timely detection of intraoperative temperature abnormalities and accurate reflection of core temperature, but also allows for continuous dynamic tracking of patient temperature changes [25–27].

Therefore, the aim of this study is to investigate whether the combination of wireless temperature monitoring and preoperative pre-warming can prevent perioperative hypothermia and related complications in patients undergoing elective laparoscopic colorectal cancer surgery.

2. Methods

2.1 Study design and patients

This study was conducted in accordance with the principles of the Declaration of Helsinki and CONSORT guidelines. The ethical part of it has been approved by the Clinical Research Committee at the First Affiliated Hospital of Wenzhou Medical University. The study was registered in the National Medical Research Registration and Filing Information System and approved by the institutional review board (Registration Nos.: MR-33-26-025750 and pid: 318579). The trial was also prospectively registered with the Chinese Clinical Trial Registry (ChiCTR; registration number: ChiCTR2600124213) (https://www.chictr.org.cn/index.html).Written informed consent was obtained from all participants. Consecutive eligible patients were enrolled from January 1, 2024. Patient selection for this study was based on the following criteria: The inclusion criteria comprised 1) Patients aged 18–75 years, regardless of gender; 2) Patients scheduled for elective laparoscopic radical resection of colorectal cancer under general anesthesia; 3) Provision of signed informed consent; 4) An ASA physical status classification of I to III; 5) A preoperative body temperature within the normal range; 6) A BMI of 18.5–28 kg/m²; 7) An estimated surgical duration of 2–6 hours. The exclusion criteria included 1) A history of severe skin allergy, particularly to silicone or medical plastics; 2) The need for intravenous infusion in both upper limbs (as the wireless temperature sensor needed to be placed in the armpit on the side without infusion to avoid interference from low-temperature fluids affecting the accuracy of temperature monitoring); 3) Severe immune dysfunction (e.g., hyperthyroidism, hypothyroidism, adrenal insufficiency) or sweat gland dysfunction; 4) Preoperative visual, hearing, or language communication impairments; 5) Patients with coagulation disorders, cachexia, or burns; 6) Cases requiring conversion from laparoscopic to open laparotomy.

2.2 Randomization, blinding, and interventions

An investigator not involved in the study allocated patients into the prewarming group (Group P) and the routine warming group (Group C), with 90 patients in each group, according to a random number table. The experiment commenced upon the subject's entry into the preoperative preparation room, where prewarming was administered by the team member responsible for randomization. Data collection was subsequently performed by a blinded anesthesiologist, followed by statistical analysis conducted by another investigator. All research personnel, including anesthesiologists, surgeons, and nurses, were unaware of each participant's group assignment, with the exception of the investigator responsible for randomization.

Both groups received standard warming measures, which included covering with a thin blanket upon entering the operating room, warming all intravenously administered fluids and peritoneal irrigation fluids to 38℃, maintaining operating room temperature between 21℃ and 24℃, and humidity between 40% and 60%. Moreover, continuous body temperature monitoring was initiated via a wireless temperature probe placed in the patient's axilla from the time of entry into the preoperative waiting area and establishment of intravenous access, extending throughout the preoperative preparation room, operating room, and PACU.

Patients in the prewarming group (Group P) received preoperative warming using a forced-air warming blanket set to medium temperature (38℃) applied to the torso and limbs for 30 minutes before surgery, whereas patients in the routine warming group (Group C) were only covered with a thin blanket during the same period. During surgery, both groups received forced-air warming with the upper-body blanket set to 38℃. If intraoperative body temperature fell below 36℃, the warming blanket temperature was increased to 43℃; if it exceeded 37℃, the temperature was lowered accordingly. A unified anesthesia protocol was implemented for both groups.

2.3 Results definitions

The primary outcome was the incidence of perioperative hypothermia, defined as a body temperature (T) < 36°C at any time point between T0 (entry into the operating room) and T12 (departure from the PACU). Secondary outcomes included: Core body temperature at each perioperative time point and its fluctuations in both groups (time of onset of hypothermia after induction, duration of perioperative hypothermia); Hypothermia-related complications (postoperative shivering, postoperative agitation, postoperative nausea and vomiting, delayed emergence); Quality of emergence from anesthesia (time to recovery of consciousness, extubation time, length of stay in the recovery room); Early postoperative recovery and treatment costs (time to first flatus, postoperative length of stay until discharge, total hospitalization costs); Pain status at 24 hours postoperatively (VAS score, number of patient-controlled analgesia pump compressions); Coagulation parameters preoperatively and on postoperative day 1, including activated partial thromboplastin time (APTT) and prothrombin time (PT); Inflammatory markers preoperatively and on postoperative day 1, including white blood cell count (WBC), interleukin-6, and interleukin-10; Internal environment–related indices preoperatively and on postoperative day 1, including pH and HCO_3^-.

The definitions of postoperative complications were as follows. Postoperative shivering was defined as involuntary muscle contractions occurring during the emergence period. Postoperative agitation referred to irregular movements, mainly involving the limbs, in the presence of impaired consciousness. Delayed emergence was defined as failure to regain consciousness within 1 hour in the PACU after discontinuation of anesthetics at the end of surgery. Recovery of consciousness was considered when the patient responded to verbal commands and was able to follow simple instructions (e.g., hand squeezing).

Additional baseline and perioperative variables collected included patient age, height, weight, sex, body mass index (BMI), operating room temperature, ASA physical status, type of surgery, duration of surgery, duration of anesthesia, intraoperative fluid volume, and irrigation volume.

2.4 Statistical analysis

Statistical analyses were performed using R software (version 4.5.1). Continuous variables were first tested for normality. Normally distributed data are presented as mean ± standard deviation (SD) and were compared between groups using the independent-samples t test. Non-normally distributed data are expressed as median (interquartile range, IQR) and were compared using the Mann–Whitney U test. Categorical variables are reported as number (percentage) and were compared using the χ^2 test or Fisher's exact test, as appropriate.

For outcome analyses, linear regression models were used for continuous outcomes, with results reported as regression coefficients (β) or mean differences (MD) with 95% confidence intervals (CI). Poisson regression models were used for count outcomes; when overdispersion was present, negative binomial regression was applied. Results are presented as risk ratios (RR) with 95% CI. Ordinal logistic regression was used for ordinal outcomes, and results are reported as odds ratios (OR) with 95% CI. For skewed continuous outcomes, generalized linear models with a Gamma distribution were fitted, and results are presented as ratios with 95% CI. Binary outcomes were analyzed using Poisson regression with robust standard errors to estimate relative risks (RR) and 95% CI. Subgroup analyses were conducted by including interaction terms in the regression models. All tests were two-sided, and $P < 0.05$ was considered statistically significant.

The primary outcome was the incidence of perioperative hypothermia. Previous research indicated an incidence rate of 44.5% for perioperative hypothermia[28]. Based on a preliminary pilot study, it was anticipated that preoperative warming could reduce this incidence to 24%. With an α level of 0.05 (two-sided) and a power (1-β) of 0.8, a sample size of 81 participants per group was calculated using PASS statistical software. Accounting for an anticipated 10% loss to follow-up rate, the target sample size was set at 90 participants per group, resulting in a total planned enrollment of 180 participants.

3. Results

A total of 235 patients scheduled for elective laparoscopic radical resection of colorectal cancer were screened. Forty-five patients were excluded for not meeting the inclusion/exclusion criteria. The remaining 190 patients were randomized. Among them, 6 patients were excluded due to an excessively long surgical duration, and 4 patients were excluded due to intraoperative conversion of the surgical approach. Consequently, a total of 180 patients were included in the final data analysis, as illustrated in Fig. 1. There were no statistically significant differences between the two groups in terms of age, gender, height, weight, BMI, ASA score, anesthesia duration, surgical duration, operating room temperature, intraoperative fluid volume, or irrigation volume (P > 0.05), as shown in Table 1.

Table 1
The Demographics and Baseline Characteristics of Patients

Age, (year)	**Prewarming** **N = 90**	**Routine warming** **N = 90**	***P-value***
	68.00(59.00–72.00)	**67.00(59.00–71.00)**	**0.609**
Gender, (M/F)	35/55	38/52	0.761
BMI, (kg/m2)	23.39 ± 2.29	23.06 ± 2.39	0.349
ASA (1/2/3), n	12/75/3	7/82/1	0.291
Type of Surgery, n(%)			1.000
Rectal Carcinoma	44(48.9)	45(50.0)	
Colonic Carcinoma	46(51.1)	45(50.0)	
Duration of Anesthesia, (min)	217.00(195.00,244.00)	217.50(192.75,250.00)	0.876
Duration of Surgery, (min)	178.50(159.25,213.00)	183.50(161.00,218.25)	0.796
Temperature on Admission, (℃)	36.58 ± 0.22	36.64 ± 0.28	0.153
Temperature of Operating Room, (℃)	23.00(22.00–23.00)	23.00(22.00–24.00)	0.071
Intraoperative Fluid Volume, (ml)	1500.00(1000.00-1500.00)	1500.00(1000.00-1875.00)	0.903
Intraoperative Irrigation Volume, (ml)	500.00(0.00-1000.00)	0.00(0.00-500.00)	0.085

Notes: Data are presented as mean ± standard deviation, median [interquartile range] or number (%). ASA=American Society of Anesthesiologists, BMI=body mass index.

The core body temperature of patients in the preoperative warming group was significantly higher than that of the routine warming group at all time points T1 to T9 (P < 0.05). No significant differences were observed between the two groups at time points T0 and T10 to T12 (P > 0.05), as shown in Table 2 and Fig. 2.

Table 2
Comparison of Core Body Temperature at Each Time Point Between the Two Groups (°C)

Measurement Time Points of Core Body Temperature	Groups		*P-value*
	Prewarming	**Routine warming**	
	N = 90	**N = 90**	
T0	36.58 ± 0.22	36.64 ± 0.28	0.153
T1	36.80 ± 0.31	36.65 ± 0.36	0.004*
T2	36.57 (36.38, 36.76)	35.71 (35.63, 35.86)	0.000*
T3	36.57 (36.36, 36.77)	35.71 (35.63, 35.87)	0.000*
T4	36.58 (36.30, 36.95)	36.40 (36.09, 36.79)	0.019*
T5	36.64 (36.22, 36.94)	36.34 (35.90, 36.77)	0.004*
T6	36.60 (36.20, 36.97)	36.21 (35.90, 36.87)	0.006*
T7	36.50 (36.22, 36.87)	36.30 (36.02, 36.68)	0.007*
T8	36.50 (36.10, 36.92)	36.29 (35.90, 36.72)	0.016*
T9	36.30 (36.10, 36.50)	36.00 (35.80, 36.20)	0.000*
T10	36.20 (36.10, 36.40)	36.20 (36.10, 36.40)	0.388
T11	36.30 (36.20, 36.50)	36.30 (36.20, 36.50)	0.917
T12	36.50 (36.20, 36.77)	36.50 (36.20, 36.77)	0.760

Notes: Data are presented as mean ± standard deviation, median [interquartile range] or number (%).

* $P < 0.05$, indicating a statistically significant difference between the two groups.

T0: Temperature on Admission to the Operating Room, T1: Induction, T2: Skin Incision, T3: 30 minutes after Induction, T4: 60 minutes after Induction, T5: 90 minutes after Induction, T6: 120 minutes after Induction, T7: 150 minutes after Induction, T8: End of Surgery, T9: Admission to PACU (Post Anesthesia

Care Unit), T10: 10 minutes after Admission to PACU, T11: 20 minutes after Admission to PACU, T12: Discharge from PACU.

For the primary outcome, the risk of IPH was significantly higher in the routine warming group compared to the prewarming group (RR = 2.30, 95% CI 1.50–3.53, P < 0.001). Among the secondary outcomes, except for the delayed emergence (RR = 1.16, 95% CI 0.72–1.89, P = 0.542) and PACU stay time (RR = 1.01, 95% CI 0.91–1.13, P = 0.893), where no significant differences were observed between the two groups, the prewarming group showed significantly better outcomes for all other indicators (P < 0.05). Due to the inconsistent skewness direction of hospital costs between the two groups, a Gamma GLM could not be applied. Therefore, a non-parametric test was used for inter-group comparison, which revealed that the total hospital costs were significantly lower in the prewarming group compared to the routine warming group [prewarming group 45798.87 (39580.99-53641.61), routine warming group 51312.66 (45826.97-55105.08), P = 0.008]. The number of patients requiring transfusion was 4 in each group. Additionally, we conducted an exploratory analysis on the time to onset and duration of hypothermia in the hypothermic populations of both groups. Compared to the routine warming group, patients in the prewarming group had a significantly prolonged time to onset of hypothermia and a significantly shortened duration of hypothermia, meaning a shorter intraoperative rewarming time (P < 0.05), as shown in Table 3 and Fig. 3.

Table 3
Perioperative Clinical Events and Recovery Metrics

Primary outcome	**Prewarming**	**Routine warming**	**Treatment Effect(95% CI)**	**P-value**
	N = 90	**N = 90**		
IPH, n (%)	30 (33.3)	69 (76.6)	RR 2.3 (1.5–3.53)	< 0.001
Secondary Outcome	**N = 90**	**N = 90**		
Min T (℃), median (IQR)	36.09 (35.84–36.20)	35.65 (35.57-36.00)	ROM 0.991 (0.989–0.993)	< 0.001
Shivering, n (%)	5 (5.6)	19 (21.1)	RR 3.8 (1.53–11.5)	= 0.008
Agitation, n (%)	9 (10.0)	27 (30.0)	RR 2.33 (1.1–5.37)	= 0.033
Nausea and Vomiting, n (%)	7 (7.8)	20 (22.2)	RR 2.86 (1.27,7.28)	= 0.017
Delayed Emergence, n (%)	31 (34.4)	35 (38.9)	RR 1.16 (0.72–1.89)	= 0.542
PCA Demand Attempts (times), median (IQR)	8.00 (4.00–10.00)	8.00 (6.00–16.00)	RR 1.33 (1.13–1.56)	< 0.001
Total Analgesic Consumption via PCA (ml), median (IQR)	16.00 (8.00–20.00)	30.00 (13.00–32.00)	ROM 1.53 (1.31–1.79)	< 0.001
Time to First Flatus (min), median (IQR)	42.50 (26.00–83.00)	67.00 (48.00–96.00)	ROM 1.40 (1.19–1.65)	< 0.001
Length of Stay (d), median (IQR)	9.00 (7.00–11.00)	10.00 (9.00–16.00)	ROM 1.25 (1.14–1.36)	< 0.001
Time to Regain of Consciousness (min), median (IQR)	10.00 (10.00-13.5)	15.00 (10.00–22.00)	ROM 1.41 (1.22–1.62)	< 0.001
Time to Extubation (min), median (IQR)	15.00 (15.00-23.80)	20.00 (15.00–30.00)	ROM 1.32 (1.17–1.48)	< 0.001
Length of Stay in PACU (min), median (IQR)	55.00 (44.00–68.00)	53.00 (44.20–64.00)	ROM 1.01 (0.91–1.13)	= 0.893
Patient Satisfaction (1/2/3/4), (n)	0/6/13/71	0/15/21/54	OR 0.40 (0.20–0.75)	< 0.05
VAS score (0–10), median (IQR)	3.00 (2.00–3.00)	3.00 (3.00–5.00)	OR 2.80 (1.62–4.90)	< 0.001
Exploratory Analysis	**N = 30**	**N = 69**		

Primary outcome	Prewarming	Routine warming	Treatment Effect(95% CI)	P-value
	N = 90	N = 90		
Duration of Hypothermia	30.00 (11.20–90.00)	67.50 (25.00-136.00)	ROM 1.68 (1.12–2.46)	= 0.012
Time to Hypothermia after Induction	198.00 (117.00-283.00)	88.90 (54.90–146.00)	ROM 0.51 (0.41–0.65)	< 0.001

Notes: IPH = Intraoperative Hypothermia; RR = Risk Ratio; OR = Odds Ratio; ROM = Ratio of Means; * P < 0.05, indicating a statistically significant difference between the two groups.

We tested the blood parameters of patients on the day before and the day after surgery and found no significant difference in peripheral blood coagulation markers between the two groups (P > 0.05). There were no significant differences in white blood cell count, IL-6, IL-10, and internal environment between the two groups (P > 0.05), as shown in Table 4 and Fig. 4.

Table 4
Comparison of Peripheral Blood Parameters

Coagulation Markers		Prewarming	Routine warming	P-value
	Time Points	N = 90	N = 90	
APTT (s), median (IQR)	Baseline	35.5(34.90–38.90)	36.55(33.52–37.53)	0.348
	POD1	37.90(35.30-40.65)	37.10(35.70-38.75)	0.279
PT (s), median (IQR)	Baseline	13.20(12.72–14.15)	13.20(12.90–13.70)	0.814
	POD1	14.00(13.70–14.50)	13.90(13.83–14.20)	0.282
Inflammatory Cytokine Levels				
WBC (×10^9/L), median (IQR)	Baseline	6.40(4.81–7.27)	6.07(5.05–6.87)	0.447
	POD1	8.01(6.36–11.56)	8.66(7.25–10.72)	0.400
IL-6 (pg/mL), median (IQR)	Baseline	9.19(9.02–9.52)	9.34(9.08–9.80)	0.100
	POD1	95.98(95.39–96.57)	95.98(95.12–97.02)	0.586
IL-10 (pg/mL), median (IQR)	Baseline	1.74(1.53–2.28)	1.72(1.54–2.03)	0.717
	POD1	8.00(7.73–8.54)	8.01(7.47–8.64)	0.221
Acid-Base Status				
PH	Baseline	7.40(7.36–7.42)	7.39(7.36–7.43)	0.582
	POD1	7.36(7.34–7.38)	7.36(7.35–7.38)	0.070
HCO_3^- (mmol/L), median (IQR)	Baseline	24.35(23.50–25.1)	25.00(23.70–25.70)	0.064
	POD1	23.40(21.80–25.00)	24.30(22.50–25.00)	0.168

Notes: POD1= Postoperative Day 1

Subgroup analyses revealed no statistically significant interaction effects between the warming strategies (Prewarming vs. Routine) and any of the examined baseline or surgical variables, including sex, age categories, type of carcinoma, operative duration, and BMI categories (all interaction $P > 0.05$). The risk ratios and distributions for each subgroup are presented in Table 5.

4. Discussion

Perioperative hypothermia is one of the most common complications during anesthesia and can lead to a series of hypothermia-related adverse events; therefore, perioperative temperature management warrants significant attention. The diagnostic criterion for hypothermia is a core body temperature below 36°C. Both domestic and international studies indicate that preoperative warming can significantly reduce the incidence of perioperative hypothermia. Consequently, this study investigates the effect of preoperative warming on temperature preservation in patients. Currently, the gold standard for monitoring core temperature remains pulmonary artery catheterization [29]. However, this method is invasive, expensive, and unsuitable for most routine surgical patients. Nasopharyngeal temperature monitoring is an effective method for assessing core temperature but is not applicable to awake patients or those with head injuries, and it may cause epistaxis and increase patient discomfort. Thus, there is a clinical need for a device that can accurately, continuously, and non-invasively monitor a patient's core temperature. The most widely used wireless temperature sensor in clinical practice is the iThermonitor® (RuiRen Medical Technology), which is attached to the axilla. This sensor wirelessly monitors and transmits the patient's temperature signal to a corresponding receiver, the cHub smart hub, which then displays the temperature data on a monitor [30]. This device allows for continuous perioperative temperature monitoring, facilitating the timely detection of hypothermia. Furthermore, using the same monitoring method throughout the perioperative period overcomes errors associated with switching measurement tools. Pei et al. studied the accuracy of the iThermonitor® for monitoring core temperature, reporting a mean difference of (0.14 ± 0.26)°C compared to esophageal temperature in 3,339 data pairs [26]. Therefore, in this trial, upon entering the preoperative preparation room and after obtaining consent, patients in both groups had their temperature monitored using the axillary wireless temperature sensor iThermonitor®.

The results of this study show that for patients undergoing laparoscopic radical resection for colorectal cancer under general anesthesia, adding 30 minutes of preoperative active warming to standard intraoperative measures significantly reduced the incidence of intraoperative hypothermia (IPH). The preoperative warming group exhibited higher body temperatures at all perioperative time points (T1–T9) compared to the routine warming group. Compared to the routine warming group, the preoperative warming group experienced a significantly delayed onset and a markedly shorter duration of hypothermia. The quality of anesthesia recovery also improved, with significantly shorter times to consciousness recovery and extubation, although the length of stay in the post-anesthesia care unit (PACU) showed no statistically significant difference between the two groups. Regarding postoperative complications, the incidences of postoperative shivering, agitation, and postoperative nausea and vomiting (PONV) were significantly lower in the preoperative warming group, while the incidence of delayed emergence in the recovery room showed no significant difference. Compared to the routine warming group, the preoperative warming group had a significantly shorter time to first flatus, reduced postoperative hospital stay, and lower total hospitalization costs. Furthermore, the Visual Analog Scale (VAS) scores at 24 hours postoperatively and the number of patient-controlled analgesia (PCA) pump presses were lower in the preoperative warming group. Peripheral blood coagulation function indicators showed no significant difference between the groups. Inflammatory marker results indicated that

preoperative warming did not have a protective effect against postoperative infections, and there was no difference in the acid-base balance of the internal environment between the two groups.

With China's economic development, improvements in the quality of life and healthcare envsironment, the volume of surgeries is increasing annually, and population aging has become a challenging issue. Currently, gastrointestinal tumors are among the top five most common cancers in China. According to GLOBOCAN 2018 estimates, there were approximately 1.85 million new cases of colorectal cancer worldwide, ranking it the third most common cancer globally. Colorectal cancer mortality reached approximately 880,000, making it the second leading cause of cancer death [10]. Furthermore, its complication and mortality rates increase with age [31]. Perioperative hypothermia is a common complication in patients undergoing general anesthesia. Current research identifies risk factors for perioperative hypothermia to include age, BMI, sex, anesthesia duration, operating room temperature, surgical approach, and infusion temperature [32–34]. The baseline characteristics of patients in both groups showed no significant differences, indicating comparability at baseline, as shown in Table 1. There were no significant differences in anesthesia duration, surgery duration, intraoperative fluid volume, or irrigation volume between the groups. We also conducted subgroup analyses based on age, BMI, sex, surgery duration, and surgical approach. The results showed no statistically significant differences in the intervention effect across subgroups, and no significant interactions were observed. This suggests that the preoperative warming intervention demonstrated a relatively stable and consistent effect across different population characteristics and perioperative conditions. Its clinical benefits were not significantly influenced by the aforementioned factors, indicating good generalizability and applicability. However, the sample size of this study was relatively limited, with some subgroups having small sample sizes, leading to insufficient statistical power, which may have reduced the ability to detect subgroup differences. Therefore, the possibility of undetected potential differences cannot be excluded. Future studies with larger samples and multiple centers are needed to further validate the true effect of the preoperative warming intervention in different subgroup populations.

The results of this trial indicate that for patients undergoing laparoscopic radical resection for colorectal cancer under general anesthesia, adding 30 minutes of preoperative warming in addition to routine intraoperative warming measures significantly reduced the incidence of perioperative hypothermia. Upon entering the operating room, the ambient temperature was adjusted appropriately for both groups, the same anesthesia protocol was used, and intraoperative warming was continuously applied. As confirmed by previous research, the core body temperature of patients in both groups decreased to varying degrees after anesthesia induction, but the temperature drop in the routine warming group was significantly greater than that in the preoperative warming group. At all time points after induction, the body temperature of the preoperative warming group was significantly higher than that of the control group. In this trial, the incidence of hypothermia was 33.3% in the preoperative warming group and 76.6% in the routine warming group. The incidence in the routine warming group was significantly higher than that in the preoperative warming group, with a statistically significant difference ($P < 0.001$). Compared to the routine warming group, when hypothermia occurred in the preoperative warming group, patients

returned to normal body temperature more quickly. This indicates that preoperative warming helps maintain intraoperative temperature stability in patients undergoing laparoscopic colorectal cancer surgery.

Maintaining normal body temperature is crucial for the body's metabolism. Even mild hypothermia can lead to a series of complications. Studies have shown that hypothermia slows the metabolism of anesthetic drugs, increases the incidence of postoperative shivering and agitation, thereby prolonging recovery time and lengthening the stay in the PACU [14, 15]. The results of this study similarly demonstrate that active preoperative warming stabilizes core body temperature, thereby improving the quality of recovery and reducing postoperative complications. In the preoperative warming group, the time to consciousness recovery and extubation were significantly shorter, and the incidences of postoperative shivering and PONV were significantly reduced. However, there was no significant difference in PACU stay or the incidence of delayed emergence between the two groups. This discrepancy might stem from differing hospital criteria for PACU discharge. In this study, the preoperative warming group had lower VAS scores and fewer PCA pump presses, indicating that preoperative warming can alleviate postoperative pain and reduce reliance on analgesic medication.

The Enhanced Recovery After Surgery (ERAS) protocol advocates for early mobilization, early oral intake, early extubation, and effective pain management. Prolonged bed rest is a high-risk factor for deep vein thrombosis; therefore, encouraging early postoperative ambulation helps prevent its occurrence. Extended postoperative fasting places patients in a state of stress and increases anxiety. Early oral intake is also beneficial for the recovery of gastrointestinal function. For patients undergoing abdominal surgery, factors such as surgical trauma, the inhibitory effects of anesthetic drugs, and perioperative hypothermia can all affect postoperative recovery, thereby hindering rapid rehabilitation and increasing the economic burden on patients. The results of this trial show that compared to the routine warming group, the preoperative warming group had a significantly shorter time to first flatus, achieving the goal of early oral intake. Moreover, preoperative warming shortened the postoperative hospital stay and reduced hospitalization costs. Currently, China faces a shortage of medical resources, with many patients experiencing difficulties in obtaining hospitalization. This study suggests that shortening hospital stays can improve hospital bed turnover rates, reflecting the "rapid recovery" concept, conserving medical resources, increasing hospital efficiency, and potentially enhancing patient satisfaction with treatment.

Some studies suggest a link between clinical bleeding and perioperative hypothermia. Surgeons have long suspected that hypothermia leads to coagulopathy and increases perioperative blood loss. Currently, it is believed that temperature-related coagulation disorders primarily involve effects on platelet function, coagulation factor enzymatic activity, and fibrinolysis [36]. Doufas's study [14][36] indicated that a core temperature drop of only 1.68°C increased blood loss by 30% (approximately 500 ml) and significantly increased the need for allogeneic blood transfusion. Conversely, another similar study failed to establish a relationship between blood loss and temperature during the perioperative period. Currently, it is believed that patients with malignant tumors have a higher risk of thrombotic

diseases than the general population, mainly due to the following reasons [35]: ▯ The complex interaction between the tumor focus and host cells disrupts the balance between fibrinogen and coagulation factors; ▯ Tumor cells stimulate angiogenesis by promoting the release of pro-angiogenic factors, which in turn prompts vascular endothelial cells to produce procoagulant substances, promoting thrombosis in patients; ▯ Tumor tissue damages surrounding blood vessels, causing blood flow obstruction. Therefore, this study investigated the impact of perioperative hypothermia on coagulation function in colorectal cancer patients. The assessment of coagulation function in this study involved measuring peripheral blood coagulation parameters preoperatively and on the first postoperative day. The results showed no significant difference in coagulation function between the two groups. This might be because the observation of coagulation parameters in this study was based on isolated time points, not continuous data, and the data might have a lag. The number of patients requiring intraoperative blood transfusion was the same in both groups, which might be related to the similar severity of perioperative hypothermia in both groups. Furthermore, the surgical approach in this study was laparoscopic, which involves smaller incisions and consequently less bleeding.

This study also compared early inflammatory markers between the groups regarding the effect of preoperative warming. The results showed no significant differences in white blood cell count (WBC), interleukin-6 (IL-6), or interleukin-10 (IL-10) on the first postoperative day between the two groups ($P > 0.05$). Kurz et al.'s study [17] demonstrated that a core temperature drop of only 1.9°C could triple the incidence of surgical site infection after colon resection. Subsequently, numerous studies have also indicated a close association between perioperative hypothermia and postoperative surgical infections [36, 37]. As research on body temperature and postoperative infections expands, some studies have begun to question this correlation. For example, Baucom et al. [38], investigating from different definitions of hypothermia, found no association between perioperative hypothermia and surgical site infection (SSI) in patients undergoing colorectal cancer surgery. Therefore, the correlation between perioperative hypothermia and infection still requires substantial research for confirmation. This study indicates that perioperative hypothermia is not associated with early postoperative infections in the observed patients. However, this study only examined the lack of correlation in early postoperative infections and did not discuss whether there were differences in infection rates over a longer postoperative period between the two groups.

Limitations of this study: (1) This was a single-center study with a small sample size. Future multi-center studies with larger datasets are needed to provide more compelling evidence. (2) The surgical teams involved were not uniform, which might have introduced bias into the results. (3) The patients selected for this study underwent minimally invasive surgery. The impact of preoperative warming combined with routine warming measures on patients undergoing open surgery requires further verification. (4) Because the wireless temperature monitoring system was not available in the wards, changes in patients' body temperature during the postoperative ward stay were not studied. Future research could investigate this aspect.

In conclusion, for patients undergoing laparoscopic radical resection for colorectal cancer under general anesthesia, relying solely on routine intraoperative warming measures did not significantly improve the incidence of perioperative hypothermia. However, perioperative temperature monitoring with the wireless temperature sensor iThermonitor®, combined with preoperative warming and continuous intraoperative routine warming measures, effectively reduced the incidence of perioperative hypothermia, decreased perioperative/postoperative complications, improved the quality of patient recovery, and was beneficial for postoperative gastrointestinal function recovery in patients.

Conclusion

In conclusion, 30 minutes of preoperative prewarming combined with wireless dynamic temperature monitoring enabled us to achieve continuous dynamic temperature monitoring throughout the perioperative period. We found that prewarming significantly reduced the incidence of perioperative hypothermia in patients undergoing laparoscopic radical resection of colorectal cancer, delayed the onset and shortened the duration of hypothermia, and improved the quality of postoperative recovery. These findings are consistent with the ERAS concept and provide high-level clinical evidence for future research on perioperative temperature protection.

Abbreviations

CRC (Colorectal Cancer Resection)

IPH (Intraoperative Hypothermia)

ERAS (Enhanced Recovery After Surgery)

PACU (Post Anesthesia Care Unit)

ICU (Intensive Care Unit)

ASA (American Society of Anesthesiologists)

BMI (Body Mass Index)

VAS (Visual Analog Scale)

APTT (Activated Partial Thromboplastin Time)

PT (Prothrombin Time)

WBC (White Blood Cell Count)

SD (Standard Deviation)

IQR (Interquartile Range)

MD (Mean Differences)

CI (Confidence Intervals)

RR (Risk Ratio)

OR (Odds Ratios)

ROM (Ratio of Means)

POD1 (Postoperative Day 1)

Declarations

Data Availability Statement

Due to privacy restrictions, the raw data supporting this study are not publicly available but can be requested from the corresponding author.

Acknowledgments

The authors extend their sincere gratitude to all patients who participated in this randomized controlled trial for their cooperation and trust. Appreciation is also extended to the nursing and surgical staff of the Departments of Anesthesiology and Gastrointestinal Surgery at the First Affiliated Hospital of Wenzhou Medical University, for their valuable assistance with perioperative temperature monitoring and data collection.

Funding

This research received no external funding.

Credit authorship contribution statement

Xiangying Gao: Writing-original draft, data curation, formal analysis, visualization, investigation. Yanyan Li: Writing-review, Conceptualization. Wenwen Du: Writing-editing, formal analysis. Xiuxiao Zhu: investigation, data collection. Xiujie Wu: investigation, data collection. Sunrui Yu: investigation, data collection. Junlu Wang: Supervision, Project administration. Qinxue Dai: Supervision, Project administration.

Ethics approval and consent to participate

This study was conducted in accordance with the principles of the Declaration of Helsinki and CONSORT guidelines. The ethical part of it has been approved by the Clinical Research Committee at the First Affiliated Hospital of Wenzhou Medical University (2026-100). The study was registered in the National Medical Research Registration and Filing Information System and approved by the institutional review

board (Registration Nos.: MR-33-26-025750 and pid: 318579). The trial was also prospectively registered with the Chinese Clinical Trial Registry (ChiCTR; registration number: ChiCTR2600124213) (https://www.chictr.org.cn/index.html).Written informed consent was obtained from all participants.

Consent for publication

Not applicable.

Competing interest

This manuscript entails no conflicts of interest. It is approved by all authors for publication and is solely submitted to this journal. We affirm that the work is original, unpublished, and not under consideration for publication elsewhere in any form. No funding was provided by any corporation or association for this study.

References

1. SESSLER D I. Perioperative thermoregulation and heat balance[J/OL]. The Lancet. 2016, 387(10038): 2655–2664[2025-05-17]. https://linkinghub.elsevier.com/retrieve/pii/S0140673615009812
2. Ljungqvist O, Scott M, Fearon KC. Enhanced Recovery After Surgery A Review [J]. JAMA Surg. 2013;152(3):292–8.
3. □□□ □□□. □□□, □. □□ ERAS □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ [J]. □□□□. 2022;33(17):2306–8.
4. None. Recommended Practices for the Prevention of Unplanned Perioperative Hypothermia [J]. AORN J. 2007;85(5):972–88.
5. □□□ □□. □□□□□□□□□□□□□□□□(2017)[J]. □□□□□□, 2017, 8□06□: 352-8.
6. BASHAW MA, Journal AORN. 2016, 103(3): 304–13[2026-02-03]. https://aornjournal.onlinelibrary.wiley.com/doi/10.1016/j.aorn.2016.01.009
7. KNAEPEL A. Inadvertent Perioperative Hypothermia: A Literature Review[J/OL]. Journal of Perioperative Practice, 2012, 22(3): 86–90[2026-02-03]. https://journals.sagepub.com/doi/10.1177/175045891202200302
8. □□□ □□. □□, □. □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ [J]. □□□□□□. 2020;19(01):34–8.
9. □□□. □□□□□□□□□□□□□□□□□□ [J]. □□□□:□□□. 2008;22(2A):290–1.
10. BRAY F, FERLAY J, SOERJOMATARAM I. el al. Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries[J/OL]. CA: A Cancer Journal for Clinicians, 2018, 68(6): 394–424[2026-02-03]. https://acsjournals.onlinelibrary.wiley.com/doi/10.3322/caac.21492
11. □□□. □□□□□□□□□□□□□□□□□□□□□□□□□□□□ [J]. □□□□□□. 2020;9(01):211–2.
12. RIPOLLÉS-MELCHOR J, RAMÍREZ-RODRÍGUEZ J M, CASANS-FRANCÉS R. Association Between Use of Enhanced Recovery After Surgery Protocol and Postoperative Complications in Colorectal

Surgery: The Postoperative Outcomes Within Enhanced Recovery After Surgery Protocol (POWER) Study[J/OL]. JAMA Surg. 2019;154(8):725. https://jamanetwork.com/journals/jamasurgery/fullarticle/2732442. [2026-02-03].

13. MEHTA O H, BARCLAY KL. Perioperative hypothermia in patients undergoing major colorectal surgery[J/OL]. ANZ J Surg. 2014;84(7–8). 10.1111/ans.12369. 550–555[2026-02-03]. https://onlinelibrary.wiley.com/doi/.
14. DOUFAS AG. Consequences of inadvertent perioperative hypothermia[J/OL]. Best Practice & Research Clinical Anaesthesiology, 2003, 17(4): 535–549[2025-05-18]. https://linkinghub.elsevier.com/retrieve/pii/S1521689603000521
15. WOBB SEAMONMJ, GAUGHAN J. J P, el al. The Effects of Intraoperative Hypothermia on Surgical Site Infection: An Analysis of 524 Trauma Laparotomies[J/OL]. Annals of Surgery, 2012, 255(4): 789–795[2025-05-18]. https://journals.lww.com/00000658-201204000-00026
16. Frank SM, Fleisher LA, Breslow MJ, et al. Perioperative maintenance of normothermia reduces the incidence of morbid cardiac events. A randomized clinical trial [J]. JAMA. 1997;277(14):1127–34.
17. Kurz A, Sessler DI, Lenhardt R. Perioperative normothermia to reduce the incidence of surgical-wound infection and shorten hospitalization. Study of Wound Infection and Temperature Group [J]. N Engl J Med. 1996;334(19):1209–15.
18. MOOLA S, LOCKWOOD C. Effectiveness of strategies for the management and/or prevention of hypothermia within the adult perioperative environment[J/OL]. International Journal of Evidence-Based Healthcare, 2011, 9(4): 337–345[2025-05-17]. https://journals.lww.com/01258363-201112000-00002
19. Sun Z, Honar H, Sessler DI, et al. Intraoperative Core Temperature Patterns, Transfusion Requirement, and Hospital Duration in Patients Warmed with Forced Air [J]. Anesthesiology. 2015;122(2):276–85.
20. Olle Ljungqvist M, Scott, Kenneth C, et al. Enhanced Recovery After SurgeryA Review[J]. JAMA Surg. 2017;152(3):292–8. 10.1001/jamasurg.2016.4952.
21. [illegible] [J]. [illegible]. 2023;48(4):476–81.
22. HE LP, LIU P Z, WEN YM. el al. Effect of temperature maintenance by forced-air warming blankets of different temperatures on changes in inflammatory factors in children undergoing congenital hip dislocation surgery[J/OL]. Chinese Medical Journal, 2020, 133(15): 1768–1773[2026-02-03]. https://journals.lww.com/10.1097/CM9.0000000000000846
23. SHAW C A, STEELMAN V M, DEBERG J. el al. Effectiveness of active and passive warming for the prevention of inadvertent hypothermia in patients receiving neuraxial anesthesia: A systematic review and meta-analysis of randomized controlled trials[J/OL]. Journal of Clinical Anesthesia, 2017, 38: 93–104[2026-02-03]. https://linkinghub.elsevier.com/retrieve/pii/S0952818016304056
24. [illegible] [J]. [illegible]. 2021;37(01):89–94.
25. LIU Y, LIU C, GAO M, el al. Evaluation of a wearable wireless device with artificial intelligence, iThermonitor WT705, for continuous temperature monitoring for patients in surgical wards: a

prospective comparative study[J/OL]. BMJ Open. 2020;10(11). 10.1136/bmjopen-2020-039474. https://bmjopen.bmj.com/lookup/doi/. e039474[2025-03-10].

26. PEI L, HUANG Y, MAO G. el al. Axillary Temperature, as Recorded by the iThermonitor WT701, Well Represents Core Temperature in Adults Having Noncardiac Surgery[J/OL]. Anesthesia & Analgesia, 2018, 126(3): 833–838[2025-03-10]. https://journals.lww.com/00000539-201803000-00022
27. DOWNEY C, NG S. JAYNE D, el al. Reliability of a wearable wireless patch for continuous remote monitoring of vital signs in patients recovering from major surgery: a clinical validation study from the TRaCINg trial[J/OL]. BMJ Open, 2019, 9(8): e031150[2026-02-03]. https://bmjopen.bmj.com/lookup/doi/10.1136/bmjopen-2019-031150
28. YI J, LEI Y, XU S, el al. Intraoperative hypothermia and its clinical outcomes in patients undergoing general anesthesia: National study in China[J/OL]. PLoS ONE. 2017;12(6). https://dx.plos.org/10.1371/journal.pone.0177221. e0177221[2025-04-14].
29. KRIZANAC D, STRATIL P. HOERBURGER D, el al. Femoro-iliacal artery versus pulmonary artery core temperature measurement during therapeutic hypothermia: An observational study[J/OL]. Resuscitation, 2013, 84(6): 805–809[2025-05-18]. https://linkinghub.elsevier.com/retrieve/pii/S0300957212009240
30. □□ □□□. □□□, □. □□□□□□□ iThermonitor□□□□□□□□□□□□□□□ [J]. □□□□. 2020;34(12):2068–72.
31. □□□ □□. □□□, □. 2015□□□□□□□□□□□□□□□□□ [J]. □□□□□□. 2020;30(04):241–5.
32. HUANG C Y YANGL, ZHOU Z B, □. Risk factors for hypothermia in patients under general anesthesia: Is there a drawback of laminar airflow operating rooms? A prospective cohort study[J/OL]. Int J Surg. 2015;21:14–7. https://linkinghub.elsevier.com/retrieve/pii/S1743919115003623. [2025-05-18].
33. COLLINS S, BUDDS M, RAINES C. el al. Risk Factors for Perioperative Hypothermia: A Literature Review[J/OL]. Journal of PeriAnesthesia Nursing, 2019, 34(2): 338–346[2025-05-18]. https://linkinghub.elsevier.com/retrieve/pii/S1089947218301473
34. PEI L, HUANG Y, XU Y. Effects of Ambient Temperature and Forced-air Warming on Intraoperative Core Temperature: A Factorial Randomized Trial[J/OL]. Anesthesiology. 2018;128(5):903–11. 10.1097/ALN.0000000000002099. https://journals.lww.com/. [2025-05-18].
35. FALANGA A, MARCHETTI M. Coagulation and cancer: biological and clinical aspects[J/OL]. J Thromb Haemost. 2013;11(2):223–33. https://linkinghub.elsevier.com/retrieve/pii/S1538783622111141. [2025-05-18].
36. SIDDIQIUI T, PAL K M I SHAUKATF. el al. Association Between Perioperative Hypothermia and Surgical Site Infection After Elective Abdominal Surgery: A Prospective Cohort Study[J/OL]. Cureus, 2020[2025-05-18]. https://www.cureus.com/articles/41516-association-between-perioperative-hypothermia-and-surgical-site-infection-after-elective-abdominal-surgery-a-prospective-cohort-study
37. DEREN M E, MACHAN J T, DIGIOVANNI C, W. Prewarming Operating Rooms for Prevention of Intraoperative Hypothermia During Total Knee and Hip Arthroplasties[J/OL]. J Arthroplast. 2011;26(8):1380–6. https://linkinghub.elsevier.com/retrieve/pii/S0883540310006753. [2025-05-18].

38. LEHTINEN SJ, ONICESCU G, KUHN K M. el al. Normothermia to Prevent Surgical Site Infections After Gastrointestinal Surgery: Holy Grail or False Idol?[J/OL]. Annals of Surgery, 2010, 252(4): 696–704[2025-05-18]. https://journals.lww.com/00000658-201010000-00016

Figures

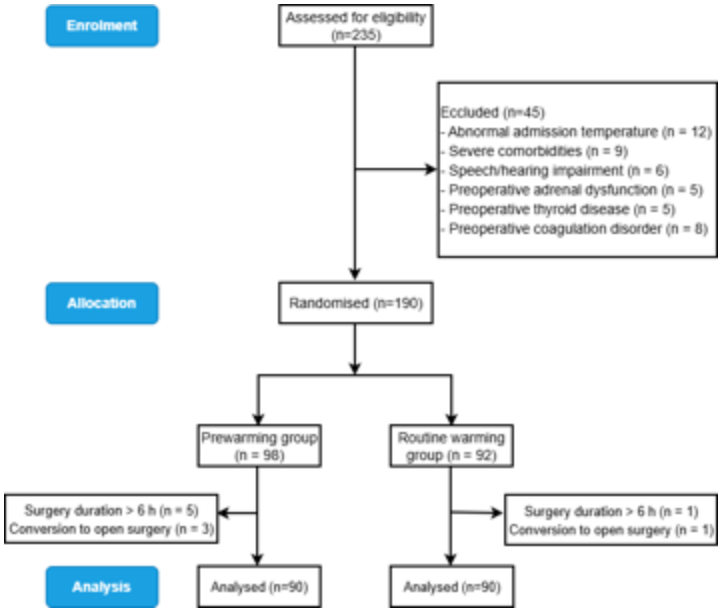


Figure 1

Flowchart

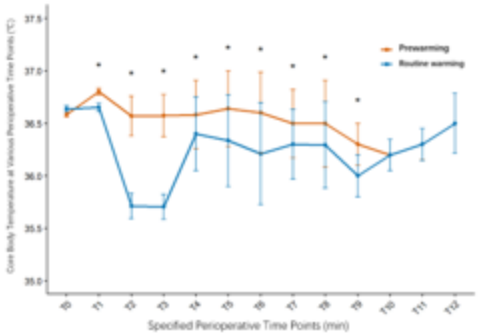


Figure 2

Comparison of Core Body Temperature at Each Time Point Between the Two Groups

Notes: * P < 0.05, indicating a statistically significant difference between the two groups.

T0: Temperature on Admission to the Operating Room, T1: Induction, T2: Skin Incision, T3: 30 minutes after Induction, T4: 60 minutes after Induction, T5: 90 minutes after Induction, T6: 120 minutes after Induction, T7: 150 minutes after Induction, T8: End of Surgery, T9: Admission to PACU (Post Anesthesia

Care Unit), T10: 10 minutes after Admission to PACU, T11: 20 minutes after Admission to PACU, T12: Discharge from PACU.

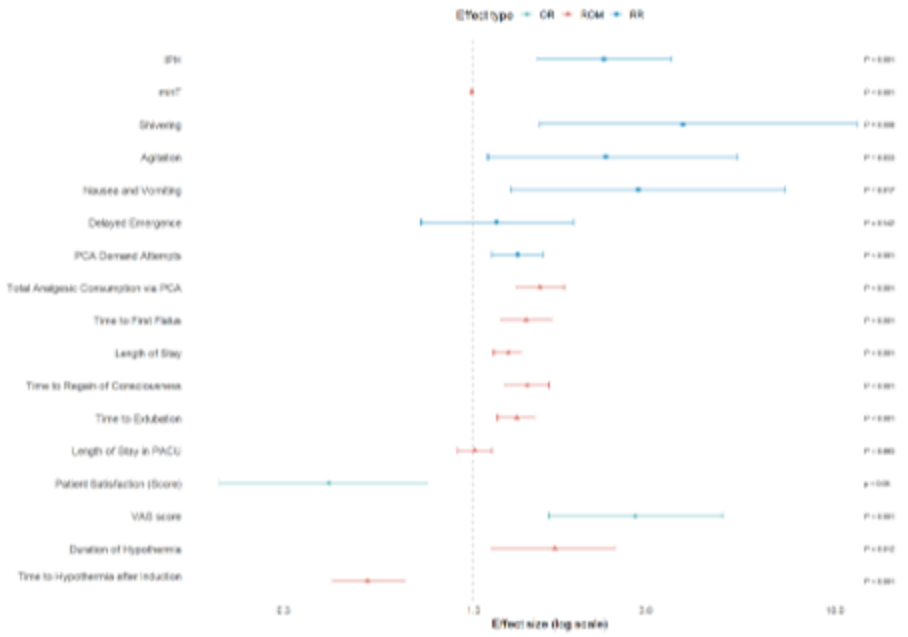


Figure 3

Perioperative Clinical Events and Recovery Metrics

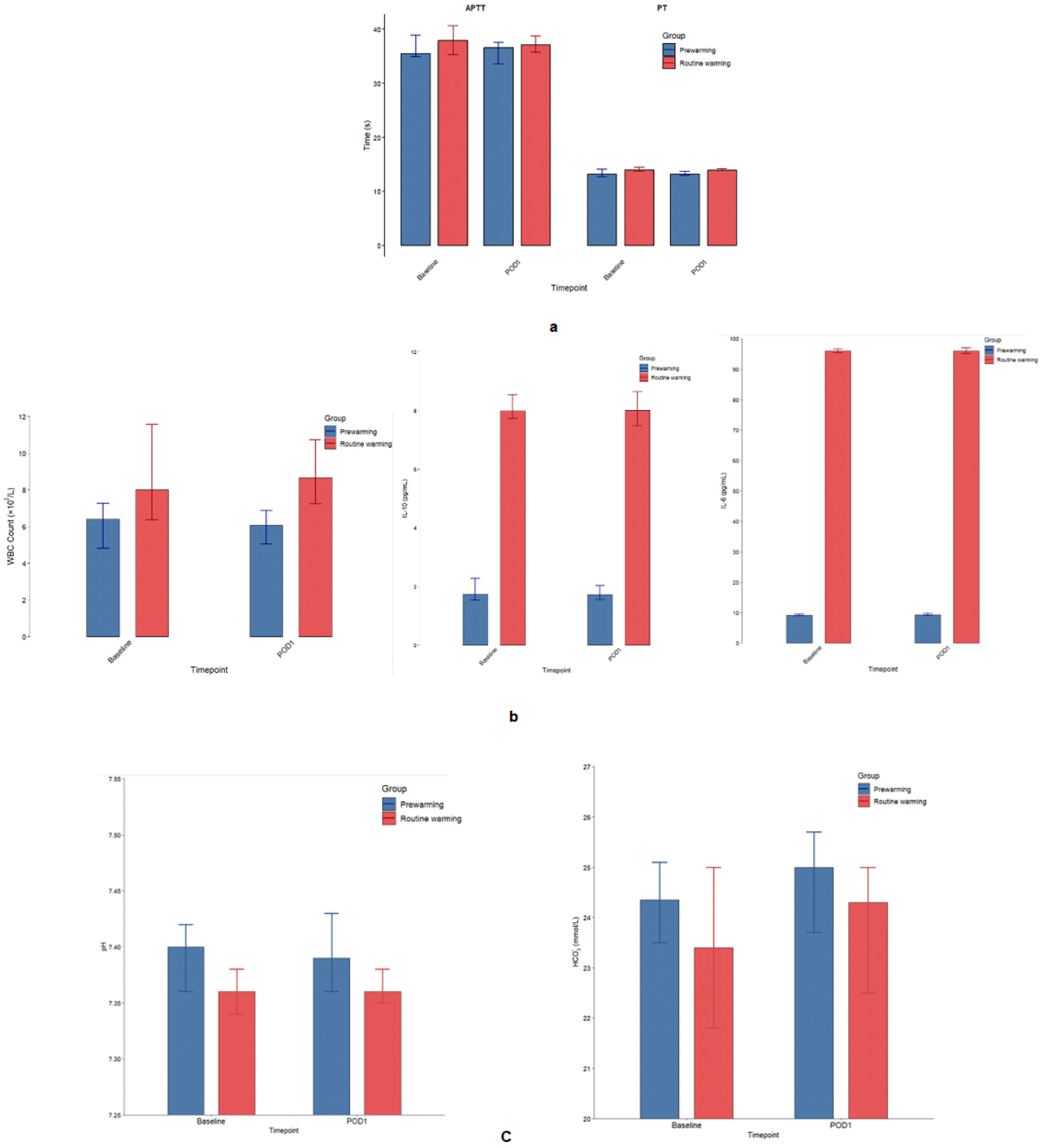


Figure 4

a. Coagulation Markers; b. Inflammatory Cytokine Levels; c. Acid-Base Status