Research Square

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Intraoperative Temperature Trajectories and Early Postoperative Recovery in Older Patients Undergoing Noncardiac Surgery: A Retrospective Cohort Study

Jing Chen
The First Affiliated Hospital of Soochow university
JU QIAN
The First Affiliated Hospital of Soochow university
Dan Zhao
The First Affiliated Hospital of Soochow university
Wanwen Wang
The First Affiliated Hospital of Soochow university
Jun LV
The First Affiliated Hospital of Soochow university
Xiaorui Feng
Jiangnan University Affiliated Hospital
Fen Cao
The First Affiliated Hospital of Soochow university
Wenyu Tang
twy824824@sina.com
The First Affiliated Hospital of Soochow university

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Abstract

Objective

To identify distinct intraoperative temperature trajectories in older patients undergoing noncardiac surgery and evaluate their association with delayed postanesthesia care unit (PACU) recovery.

Methods

This single-center retrospective cohort study included patients aged ≥ 65 years who underwent noncardiac surgery under general anesthesia with an operative duration of ≥ 2 h between January 2020 and December 2024. Core temperatures recorded within 5 min after anesthesia induction and at 30, 60, 90, and 120 min thereafter were analyzed using latent class growth modeling. Delayed PACU recovery was defined as a PACU length of stay exceeding the 75th percentile of the study population (> 70 min). Multivariable logistic regression was used to evaluate the association between temperature trajectory membership and delayed PACU recovery.

Results

Among 35,281 screened patients, 12,570 were included in temperature trajectory modeling, and 7,854 with available PACU outcome data were included in the primary analysis. Three trajectories were identified: a high-temperature trajectory (C1), an intermediate-temperature trajectory (C2), and a low-temperature trajectory (C3). All trajectories declined after anesthesia induction, but C3 had the lowest early temperature and the steepest subsequent decline. Delayed PACU recovery occurred in 1,894 patients (24.1%), with incidences of 21.0%, 24.1%, and 26.9% in C1, C2, and C3, respectively. After multivariable adjustment, C3 was associated with a higher risk of delayed PACU recovery compared with C1 (odds ratio and 95% confidence interval: 1.31, 1.09–1.56; P = 0.003), whereas C2 was not (1.13, 0.97–1.32; P = 0.130).

Conclusion

A low intraoperative temperature trajectory was independently associated with delayed PACU recovery in older patients undergoing noncardiac surgery lasting ≥ 2 h. Longitudinal temperature patterns may help identify patients at increased risk of delayed early postoperative recovery, although prospective studies are needed to confirm causality and determine whether modifying these patterns improves recovery.

Introduction

Intraoperative hypothermia is a common perioperative complication during general anesthesia and remains clinically relevant despite routine temperature monitoring and active warming measures. In large surgical cohorts, its incidence has remained high, including 44.3% in a national multicenter study in China, 29.0% in laparoscopic abdominal surgery, and 62.5% in elderly abdominal surgery [1–3]. Older adults are particularly susceptible because aging impairs thermoregulatory vasoconstriction, reduces metabolic heat production, and diminishes physiological reserve, while anesthetic agents further lower the thresholds for vasoconstriction and shivering, thereby increasing vulnerability to perioperative heat loss[4].

Intraoperative hypothermia has been associated with a wide range of adverse postoperative outcomes, including prolonged emergence from anesthesia, postoperative shivering, increased transfusion requirements, surgical site infection, and prolonged hospitalization [4–6]. A landmark randomized trial by Lenhardt et al. demonstrated that even mild intraoperative hypothermia significantly delayed recovery sufficiently to prolong post-anesthesia care unit (PACU) discharge [7]. More recent observational studies have similarly reported that intraoperative hypothermia is associated with prolonged PACU stay and delayed postoperative recovery in elderly and laparoscopic surgical populations [3, 8]. Furthermore, lower intraoperative temperatures

have been linked to postoperative delirium in older surgical patients, suggesting that perioperative thermal disturbance may adversely affect early postoperative recovery [9].

Current research on intraoperative hypothermia has primarily focused on its incidence, risk factors, and the effectiveness of preventive warming strategies [10, 11]. Most studies have evaluated intraoperative temperature using static indicators, such as the occurrence of hypothermia, the lowest intraoperative temperature, end-of-surgery temperature, or temperature measured at a single time point [10, 11]. However, intraoperative body temperature is a dynamic physiological variable that changes continuously throughout anesthesia and surgery [12]. Latent class growth modeling (LCGM) is a statistical method for identifying subgroups of patients with similar longitudinal patterns based on repeated measurements over time. Previous trajectory-based studies in laparoscopic hysterectomy and thoracoscopic surgery have demonstrated heterogeneous intraoperative temperature patterns and explored factors associated with trajectory membership [13, 14]. More recently, Cho et al. reported that early postoperative temperature trajectories were associated with severe acute kidney injury after valvular heart surgery, suggesting that longitudinal temperature patterns may provide prognostic information beyond a single temperature measurement [15]. Recovery in the PACU is an important indicator of early postoperative recovery quality. Delayed PACU recovery not only increases postoperative monitoring and nursing workload but may also indicate impaired perioperative recovery. Although previous studies have demonstrated that intraoperative hypothermia is associated with delayed emergence and prolonged PACU stay, whether distinct intraoperative temperature trajectories are independently associated with delayed PACU recovery remains unknown.

Therefore, using a large perioperative database, we applied LCGM to identify intraoperative temperature trajectories in older patients undergoing noncardiac surgery and further investigated the association between trajectory membership and delayed PACU recovery. We hypothesized that patients following lower-temperature trajectories would have a higher risk of delayed PACU recovery. Our findings may provide evidence to support individualized perioperative thermal management and early identification of patients at increased risk of delayed postoperative recovery.

Methods

Study design

This retrospective cohort study was conducted at the First Affiliated Hospital of Soochow University, Suzhou, China. The study was approved by the Institutional Ethics Committee of the First Affiliated Hospital of Soochow University (Institutional Review Board Approval No. 2024704) and registered in the Chinese Medical Research Registration Information system (ChiCTR2400094990). The requirement for informed consent was waived because of the retrospective nature of the study. This study was reported following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [16]. Perioperative data were obtained from the institutional perioperative research database, which integrates information from the electronic medical record system and anesthesia information management system. Demographic characteristics, comorbidities, surgical information, intraoperative physiological variables, and PACU recovery outcomes were extracted retrospectively for analysis.

Study population

Patients undergoing surgery between January 2020 and December 2024 were screened from the institutional perioperative research database.

Inclusion criteria were: (1) age ≥ 65 years; (2) American Society of Anesthesiologists (ASA) physical status classification I–III [17]; (3) noncardiac surgery performed under general anesthesia; (4) operative duration ≥ 2 h; and (5) availability of intraoperative temperature measurements.

Exclusion criteria were: (1) urologic surgery; (2) absence of intraoperative temperature records; and (3) implausible temperature values identified during data cleaning.

Temperature measurement

Core temperature was monitored using a nasopharyngeal probe inserted after induction of general anesthesia. In accordance with routine institutional practice, the insertion depth was estimated from the distance between the nasal tip and the earlobe. For trajectory modeling, the first temperature recorded within 5 min after induction was designated as the baseline value. Temperatures recorded at 30, 60, 90, and 120 min after induction were subsequently extracted for analysis.

Outcome definition

The primary outcome was delayed PACU recovery. PACU recovery time was defined as the duration from PACU admission to discharge. Delayed PACU recovery was defined as a PACU length of stay greater than the 75th percentile of the study population[18].

Temperature trajectory modelling

LCGM was used to identify distinct intraoperative temperature trajectories based on temperature measurements obtained at baseline and 30, 60, 90, and 120 min after anesthesia induction. Missing temperature measurements at individual time points were coded as − 999 and treated as missing values in Mplus. Parameter estimation was performed using full-information maximum likelihood (FIML) estimation, allowing patients with partially missing temperature measurements to contribute available data to trajectory modelling. Model selection was based on the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), adjusted Bayesian Information Criterion (aBIC), entropy, Lo-Mendell-Rubin likelihood ratio test (LMR), and bootstrap likelihood ratio test (BLRT). Lower AIC, BIC, and aBIC values indicated better model fit, whereas entropy values > 0.80 indicated acceptable classification accuracy. A p-value less than 0.05 in either test indicated that the model with k classes provided a significantly better fit than the model with k–1 classes[19]. Models were retained only when all trajectory groups contained at least 5% of the study population. The final model was selected after considering model fit indices, entropy, trajectory size, and clinical interpretability.

Statistical analysis

Continuous variables were expressed as means with standard deviation (SD) or medians and interquartile ranges (IQR) depending on the data distribution. Categorical variables were expressed as numbers (n) with percentages (%).

After trajectory classification, demographic, clinical, and perioperative characteristics were compared among trajectory groups using one-way analysis of variance (ANOVA) or the Kruskal–Wallis test for continuous variables and the χ^2 test for categorical variables.

PACU outcomes, including PACU length of stay and delayed PACU recovery, were compared across trajectory groups using the Kruskal–Wallis test and χ^2 test, as appropriate.

Variables with a P value < 0.10 in the univariable analyses, together with clinically relevant covariates identified a priori from previous literature, were entered into the multivariable logistic regression model to evaluate the independent association between intraoperative temperature trajectories and delayed PACU recovery.

Patients with missing PACU outcome data were excluded from the primary analysis, and no data imputation was performed. LCGM was performed using Mplus 8.0. Descriptive statistics, group comparisons, and logistic regression analyses were conducted using SPSS 26.0. Figures were generated using R software. The statistical significance level was set to two-sided 0.05.

Results

A total of 35,281 patients undergoing noncardiac surgery under general anesthesia between January 2020 and December 2024 were screened from the institutional perioperative database. After excluding patients without intraoperative temperature records (n = 17,689) and those with implausible temperature values identified during data cleaning ((n = 5,022), 12,570 patients were included in temperature trajectory modelling analysis. Among these patients, 7,854 with available PACU outcome data were further included in the final analysis evaluating the association between intraoperative temperature trajectories and delayed PACU recovery. Delayed PACU recovery occurred in 1,894 patients (24.1%) **(**Fig. 1**)**.

Identification intraoperative temperature trajectories

Model fit indices for the LCGM are shown in Table 1. With an increasing number of classes, the AIC, BIC, and aBIC values progressively decreased. Although the four-class model yielded slightly lower information criteria than the three-class model, examination of the trajectory patterns indicated that the additional class provided limited clinical differentiation. Therefore, the three-class solution was selected after considering model fit, class size, and clinical interpretability. The entropy value for the three-class model was 0.877, indicating good classification performance. The corresponding class proportions were 24.4%, 51.4%, and 24.2%, respectively.

Table 1
Model fit indices for intraoperative temperature trajectories (n = 12,570)

Categories	AIC	BIC	aBIC	Entropy	LMR	ALMR	BLRT	Class probability
1	98296.413	98348.486	98326.241					1
2	69886.413	69960.804	69929.025	0.850	< 0.001	< 0.001	< 0.001	.505/ .495
3*	**56085.292**	**56182.000**	**56140.687**	**0.877**	**< 0.001**	**< 0.001**	**< 0.001**	**.244/ .514/.242**
4	49202.052	49321.077	49270.231	0.872	0.0038	0.0045	< 0.001	.138/ .368/.374/.120
5	44719.566	44860.908	44800.528	0.878	0.0050	0.0058	< 0.001	.053/.239/.077/.370/.261

Notes: * The model with the best fit.

Abbreviations: AIC, Akaike Information Criterion; BIC, Bayesian Information Criterion; aBIC, Adjust Bayesian Information Criterion; LMR, Lo-Mendell-rubin; ALMR, Adjust Lo-Mendell-rubin; BLRT, Bootstrapped likelihood ratio test.

The three temperature trajectories were characterized based on their baseline levels and longitudinal patterns over time **(Figure 2)**. Trajectory 1 (C1) showed the highest baseline temperature (intercept = 37.078, P < 0.001) and a relatively mild decline during surgery (slope = −0.034, P < 0.001), and was defined as C1 = “high-temperature trajectory group” (24.5%). Trajectory 2 (C2), which comprised the largest proportion of patients, had an intermediate baseline temperature (intercept = 36.519, P < 0.001) and exhibited a gradual decline over time (slope = −0.047, P < 0.001), and was defined as C2 = “intermediate-temperature trajectory group” (51.1%). Trajectory 3 (C3) was characterized by the lowest baseline temperature (intercept = 36.017, P < 0.001) and the most pronounced decrease during surgery (slope = −0.075, P < 0.001), and was defined as C3 = “low-temperature trajectory group” (24.4%).

Baseline and perioperative characteristics according to trajectory groups

Baseline and perioperative characteristics according to intraoperative temperature trajectory groups are presented in **Table 2**. Among the 7,854 patients included in the PACU outcome analysis, 1,726 (22.0%), 4,199 (53.5%), and 1,929 (24.6%) were classified into the high-temperature (C1), intermediate-temperature (C2), and low-temperature (C3) trajectory groups, respectively.

Significant differences were observed among the three trajectory groups in age, sex, BMI, operative duration, blood loss, type of surgery, hypertension, and blood transfusion (all $P < 0.05$). Patients in the C3 group were generally older and had a lower prevalence of obesity than those in the C1 group. No significant differences were observed among trajectory groups in ASA physical status, diabetes, stroke history, cardiovascular disease, or intraoperative mean arterial pressure (MAP).

Table 2. Baseline and perioperative characteristics of patients included in PACU analysis (n = 7,854)

Variables	ALL	C1	C2	C3	*P* Value
	(n = 7,854)	(n = 1,726)	(n = 4,199)	(n = 1,929)	
Continuous variables					
Age, years	68 (64–73)	68 (64–72)	68 (64–73)	69 (65–73)	<0.001
MAP, mmHg	100.0 (89.7–109.7)	100.2 (89.7–110.0)	100.3 (90.0–109.8)	99.3 (88.7–109.3)	0.391
Blood loss, mL	100 (50–200)	100 (50–300)	100 (50–200)	100 (50–200)	<0.001
Operative duration, min	175 (145–225)	172 (140–220)	177 (145–225)	178 (145–225)	<0.001
Categorical variables					
Sex					<0.001
Male	3,882 (49.4)	701 (40.6)	2,020 (48.1)	1,161 (60.2)	
Female	3,972 (50.6)	1,025 (59.4)	2,179 (51.9)	768 (39.8)	
BMI					<0.001
<28 kg/m^2	6,483 (82.5)	1,321 (76.5)	3,485 (83.0)	1,677 (86.9)	
≥28 kg/m^2	1,371 (17.5)	405 (23.5)	714 (17.0)	252 (13.1)	
Type of surgery					<0.001
Orthopedic surgery	3,033 (38.6)	820 (47.5)	1,638 (39.0)	575 (29.8)	
Thoracic surgery	1,243 (15.8)	91 (5.3)	579 (13.8)	573 (29.7)	
Neurosurgery	713 (9.1)	134 (7.8)	379 (9.0)	200 (10.4)	
General surgery	2,244 (28.6)	497 (28.8)	1,284 (30.6)	463 (24.0)	
Other surgeries	621 (7.9)	184 (10.7)	319 (7.6)	118 (6.1)	
ASA					0.825
	482 (6.1)	103 (6.0)	250 (6.0)	129 (6.7)	
	6,695 (85.2)	1,473 (85.3)	3,591 (85.5)	1,631 (84.6)	
	677 (8.6)	150 (8.7)	358 (8.5)	169 (8.8)	
Hypertension					0.034
No	3,769 (48.0)	790 (45.8)	2,013 (47.9)	966 (50.1)	
Yes	4,085 (52.0)	936 (54.2)	2,186 (52.1)	963 (49.9)	
Diabetes					0.153
No	3,924 (50.0)	834 (48.3)	2,096 (49.9)	994 (51.5)	
Yes	3,930 (50.0)	892 (51.7)	2,103 (50.1)	935 (48.5)	
Stroke history					0.223
No	7,506 (95.6)	1,658 (96.1)	4,017 (95.7)	1,831 (94.9)	
Yes	348 (4.4)	68 (3.9)	182 (4.3)	98 (5.1)	
Cardiovascular disease					0.913

No	7,415 (94.4)	1,633 (94.6)	3,961 (94.3)	1,821 (94.4)	
Yes	439 (5.6)	93 (5.4)	238 (5.7)	108 (5.6)	
Blood transfusion					<0.001
No	6,243 (79.5)	1,312 (76.0)	3,346 (79.7)	1,585 (82.2)	
Yes	1,611 (20.5)	414 (24.0)	853 (20.3)	344 (17.8)	

Notes: Data are given as median (IQR) or numbers (percentages); C1, high-temperature trajectory group; C2, intermediate-temperature trajectory group; C3, low-temperature trajectory group.

Abbreviations: BMI, body mass index; MAP, mean arterial pressure; ASA, American Society of Anesthesiologists physical status classification.

MAP and blood loss had a small number of missing values and were analyzed using available data without imputation.

PACU outcomes according to trajectory groups

The median PACU length of stay in the overall cohort was 54 min (40–70). Significant differences were observed among the three trajectory groups in both PACU length of stay and the incidence of delayed PACU recovery (P < 0.001) (**Table 3**).

The median PACU length of stay was 51 (37–67) min in the high-temperature trajectory group (C1), 54 (40–70) min in the intermediate-temperature trajectory group (C2), and 55 (41–72) min in the low-temperature trajectory group (C3). Similarly, the incidence of delayed PACU recovery increased progressively across trajectory groups, occurring in 21.0%, 24.1%, and 26.9% of patients in the C1, C2, and C3 groups, respectively.

Table 3. Postoperative outcomes according to intraoperative temperature trajectory groups

Variables	ALL	C1	C2	C3	*P* Value
	(n = 7,854)	(n = 1,726)	(n = 4,199)	(n = 1,929)	
PACU length of stay, min	54 (40–70)	51(37–67)	54 (40–70)	55 (41–72)	<0.001
Delayed PACU recovery					<0.001
No	5,960 (75.9)	1,364 (79.0)	3,186 (75.9)	1,410 (73.1)	
Yes	1,894 (24.1)	362 (21.0)	1,013 (24.1)	519 (26.9)	

Notes: Data are given as presented as median (IQR) or numbers (percentages); C1, high-temperature trajectory group; C2, intermediate-temperature trajectory group; C3, low-temperature trajectory group.

Delayed PACU recovery was defined as PACU length of stay > 70 min (75th percentile).

Between-group comparisons according to delayed PACU recovery

Baseline and perioperative characteristics according to PACU recovery status are shown in **Supplementary Table S1**. Patients with delayed PACU recovery were older and had longer operative duration, greater blood loss, higher MAP, and type of surgery and temperature trajectory group compared with those without delayed recovery.

Association between temperature trajectories and delayed PACU recovery

Multivariable logistic regression analysis is shown in **Table 4**. After adjustment for potential confounders, temperature trajectory remained independently associated with delayed PACU recovery. Compared with C1, patients in C3 had a significantly higher

risk of delayed PACU recovery (OR, 1.31; 95% CI, 1.09–1.56; P = 0.003), whereas the association for C2 was not statistically significant (1.13, 0.97–1.32; P = 0.130). Other factors associated with delayed PACU recovery included longer operative duration, greater blood loss, thoracic, neurosurgical, and general surgical procedures (compared with orthopedic surgery), older age, and higher MAP. The adjusted associations between intraoperative temperature trajectories and delayed PACU recovery are visually summarized in **Figure 3**.

Table 4. Multivariable logistic regression analysis for delayed PACU recovery (n = 7,854)

Independent Variables	*OR* (95% *CI*)	*P* Value
Temperature trajectory		
C2 vs C1	1.127 (0.965–1.316)	0.130
C3 vs C1	1.307 (1.093–1.564)	**0.003**
Operative duration, per 30 min	1.036 (1.008–1.066)	0.011
Blood loss, per 100 mL	1.064 (1.034–1.095)	<0.001
Type of surgery		
Thoracic vs Orthopedic	1.359 (1.132–1.633)	0.001
Neurosurgery vs Orthopedic	1.768 (1.438–2.174)	<0.001
General vs Orthopedic	1.487 (1.280–1.728)	<0.001
Others vs Orthopedic	0.906 (0.701–1.172)	0.454
Age, year	1.023 (1.013–1.034)	<0.001
MAP, per 10 mmHg	1.025 (1.00–1.050)	0.049

Notes: C1, high-temperature trajectory group; C2, intermediate-temperature trajectory group; C3, low-temperature trajectory group.

Abbreviations: OR, odds ratio; 95%CI, 95% confidence interval.

Discussion

In this large retrospective cohort study of older patients undergoing noncardiac surgery, we identified three distinct intraoperative temperature trajectories using LCGM, characterized by progressively lower temperature levels and increasingly steep declines during the first 120 min after anesthesia induction. Delayed PACU recovery occurred in 21.0% of patients in the high-temperature trajectory group (C1), 24.1% in the intermediate-temperature trajectory group (C2), and 26.9% in the low-temperature trajectory group (C3). After multivariable adjustment, only C3 remained associated with delayed PACU recovery relative to C1 (OR, 1.31; 95% CI, 1.09–1.56), whereas C2 did not. These findings indicate that the combined pattern of a lower early core temperature and greater subsequent cooling, rather than the presence of an intraoperative temperature decline alone, identifies a subgroup at increased risk of delayed early recovery.

All three trajectories declined after induction, but they differed in both their earliest recorded temperature and subsequent rate of decline. This pattern is physiologically plausible. General anesthesia impairs thermoregulatory vasoconstriction and promotes redistribution of heat from the core to peripheral tissues, producing an early reduction in core temperature; continued environmental heat loss and reduced metabolic heat production then influence the subsequent course [5, 20]. Similar separation of intraoperative temperature curves has been described in patients undergoing laparoscopic hysterectomy and thoracoscopic surgery [13, 14]. The classes identified in our study should therefore be interpreted as data-derived summaries of thermal exposure rather than discrete biological phenotypes [19]. In particular, because the first temperature was recorded after induction, the lower intercept in C3 cannot be assumed to represent a lower preoperative core temperature.

Patients in C3 were older, had a lower BMI, and underwent longer procedures than those in C1. This clinical profile is consistent with established risk factors for perioperative hypothermia [4, 10, 11, 20]. Aging reduces the effectiveness of thermoregulatory responses, lower body mass provides less insulation, and longer procedures extend exposure to anesthetic-induced thermoregulatory impairment and environmental heat loss [4, 5, 20]. However, these between-group comparisons do not establish independent determinants of trajectory membership. They instead suggest that the low-temperature trajectory may reflect the combined influence of patient susceptibility and surgical exposure, both of which may also affect postoperative recovery.

The association between C3 and delayed PACU recovery is consistent with randomized and observational evidence linking intraoperative hypothermia to slower postanesthetic recovery and longer PACU stay [3, 7, 8]. The null estimate for C2 is also informative because it does not support a simple graded association across all three trajectories after adjustment. C3 combined the lowest early temperature with the fastest decline; consequently, the present analysis cannot determine whether the observed association was driven by temperature level, rate of cooling, duration of lower-temperature exposure, or their combination. Several mechanisms nevertheless provide biological plausibility. Mild hypothermia can increase propofol concentrations and prolong the effects of neuromuscular blocking agents, while shivering and associated discomfort may delay fulfillment of PACU discharge criteria [5, 7, 20-22]. Because anesthetic concentrations, quantitative neuromuscular recovery, and shivering were not evaluated in this study, these mechanisms remain explanatory hypotheses rather than demonstrated mediators.

Most previous studies have represented intraoperative temperature using a threshold, nadir, end-of-surgery value, or another single summary measure [10, 11, 20]. Trajectory analysis offers a different perspective by using repeated measurements to describe heterogeneity in both temperature level and change over time without imposing a single clinical cutoff [19]. Earlier trajectory studies were largely limited to specific procedures [13, 14], whereas a recent cardiac surgical cohort linked early postoperative temperature trajectories to severe acute kidney injury [15]. Our study extends this approach to a large cohort of older adults undergoing a broad range of noncardiac procedures and relates intraoperative trajectories to PACU recovery. However, we did not compare the trajectories with time-weighted average temperature, temperature nadir, end-of-surgery temperature, or other conventional metrics. The present results therefore support trajectories as a complementary description of thermal exposure, but do not establish superior prediction or incremental prognostic value over simpler temperature measures.

The clinical magnitude of the association should be interpreted cautiously. Compared with C1, C3 had a 5.9-percentage-point higher unadjusted incidence of delayed recovery and a 4-min longer median PACU stay; the adjusted association was statistically significant but modest. Such differences may have operational relevance when aggregated across a high-volume PACU, but this was not directly evaluated. Moreover, trajectory membership is an observational marker and the present data do not show that shifting a patient from one trajectory to another would shorten recovery. This distinction is important because the PROTECT trial found no reduction in major perioperative complications with aggressive warming to 37°C compared with routine thermal management targeting 35.5°C, although PACU recovery was not its primary focus [23]. Our findings therefore support consistent core-temperature monitoring, timely use of established warming measures [5, 20], and heightened attention to older patients who display lower early temperatures and continued cooling, rather than a specific or more aggressive universal temperature target. Prospective studies are needed to determine whether real-time recognition and modification of adverse thermal patterns improves PACU recovery.

Strengths and Limitations

The study has several strengths. First, this study included a large real-world cohort of older surgical patients, providing sufficient statistical power to evaluate trajectory-outcome associations. Second, rather than relying on conventional single temperature measurements, we applied latent class growth modelling to characterize longitudinal intraoperative temperature patterns. Finally, detailed perioperative data allowed adjustment for multiple potential confounders, strengthening the robustness of the observed associations.

Several limitations should be acknowledged. First, the single-center retrospective design is vulnerable to residual confounding. Information on active warming, operating-room temperature, anesthetic exposure, neuromuscular blockade and reversal, postoperative pain, nausea and vomiting, and shivering was unavailable or not included in the analysis. Second, many screened patients lacked temperature records, and PACU outcome data were unavailable for a substantial proportion of the trajectory cohort; selection bias is therefore possible. Third, trajectories were limited to the first 120 min after induction, the initial measurement was not a true preinduction baseline, and assignment to the most likely class does not fully account for classification uncertainty. Fourth, delayed recovery was defined by an institution-specific PACU length-of-stay threshold. PACU length of stay may reflect discharge practices, bed availability, and workflow as well as physiological recovery, and no direct measure of readiness for discharge was available. Finally, the findings may not generalize to younger patients, procedures lasting less than 2 h, urologic or cardiac surgery, or other institutions. External validation and prospective studies are required before the trajectories can be used to guide clinical decisions.

Conclusion

In conclusion, three distinct intraoperative temperature trajectories were identified among older adults undergoing noncardiac surgery. Compared with the high-temperature trajectory, the low-temperature trajectory was independently associated with delayed PACU recovery, whereas the intermediate-temperature trajectory was not. These findings identify a longitudinal thermal pattern associated with early postanesthetic recovery, but do not establish causality or a specific temperature target. External validation and prospective interventional studies are required.

Abbreviations

95%CI, 95% confidence interval

AIC, Akaike Information Criterion

ALMR, Adjust Lo-Mendell-rubin

aBIC, Adjust Bayesian Information Criterion

BIC, Bayesian Information Criterion

BLRT, Bootstrapped likelihood ratio test.

BMI, Body mass index

IQR, Interquartile ranges

LCGM, Latent class growth modeling

MAP, Mean arterial pressure

OR, Odds ratio

SD, Standard deviation

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Ethics Committee of the First Affiliated Hospital of Soochow University (Approval No. 2024704) and registered in the Chinese Medical Research Registration Information system (ChiCTR2400094990). The research was conducted in accordance with the principles of the Declaration of Helsinki.

Consent for publication

Not applicable.

Availability of data and materials

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

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors' contributions

J.C., J.Q. and D.Z. contributed equally to this work. W.T. and F.C. conceived and designed the study. J.C. performed the statistical analyses and drafted the manuscript. J.C., J.Q., D.Z., W.W., and J.L. collected and verified the data. X.F. provided methodological support. W.T. critically revised the manuscript and supervised the study. F.C. provided overall supervision. All authors contributed to the interpretation of the data, critically reviewed the manuscript, approved the final version for publication, and agree to be accountable for all aspects of the work.

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Figures

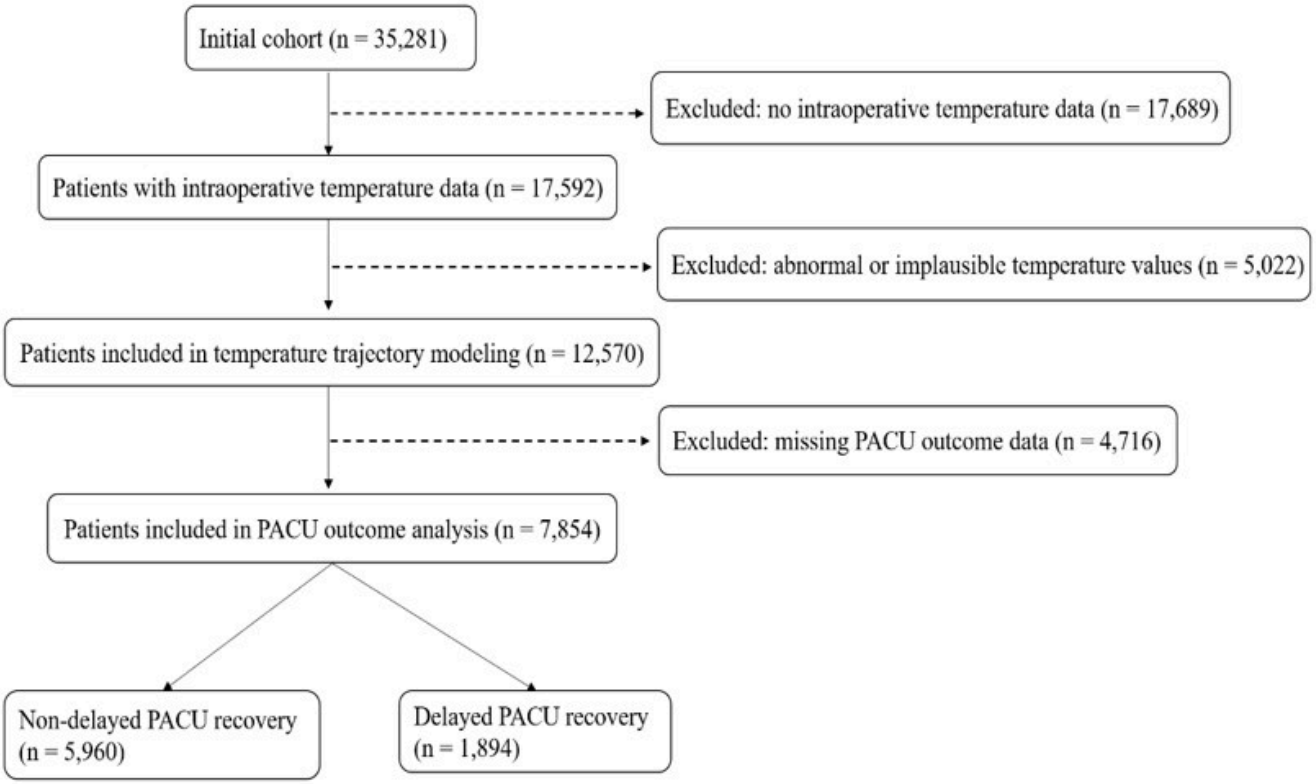


Figure 1

Flow diagram of the study

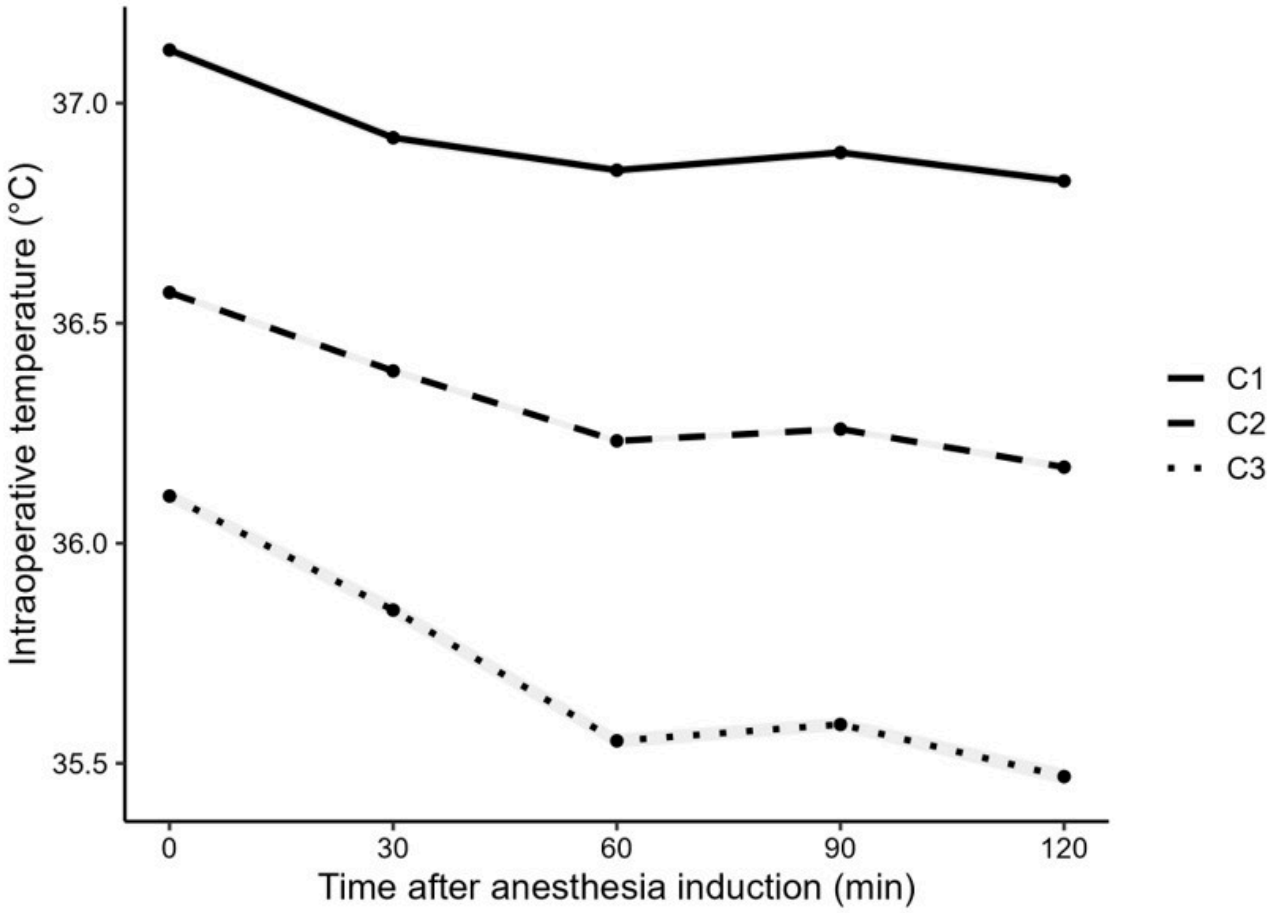


Figure 2

Intraoperative temperature trajectories.

Notes: C1, high-temperature trajectory group; C2, intermediate-temperature trajectory group; C3, low-temperature trajectory group.

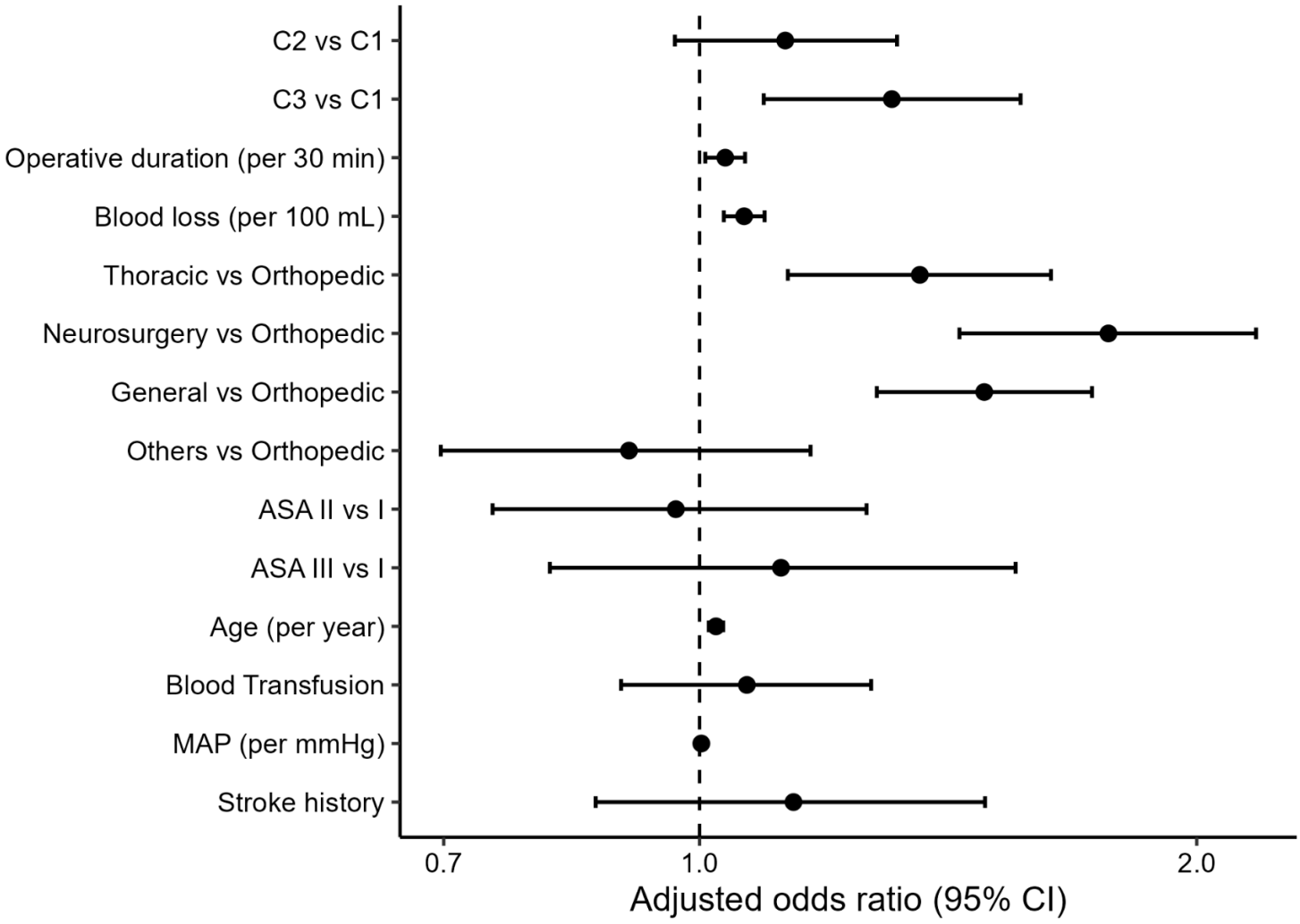


Figure 3

Legend not included with this version

Supplementary Files

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- SupplementaryTable.docx