

Analysis of the Correlation Between Perioperative Temperature Trajectory and All-Cause Mortality in Elderly Cardiac Patients

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Abstract

Background

Hypothermia following cardiac surgery can result in negative postoperative outcomes. This study aimed to identify distinct temperature trajectories using Latent Class Trajectory Modeling in elderly cardiac patients during the first three days after surgery and to assess their correlation with all-cause mortality.

Methods

This retrospective cohort study selected elderly patients who underwent cardiac surgery from the MIMIC-IV (Medical Information Mart for Intensive Care IV) database. The Latent Class Trajectory Model (LCTM) was employed to classify heterogeneous patterns of temperature changes in patients following cardiac surgery over a three-day period. Then, differences in survival across the trajectory groups were analyzed using Kaplan-Meier survival curves. The Cox regression model was used to analyze the relationship between patients' temperature trajectories post-cardiac surgery and their risk of death within one year. A subgroup analysis was performed to identify interaction factors and evaluate the robustness of this finding.

Results

A total of 1,995 cardiac surgery patients were included in the analysis. Five distinct temperature trajectory groups were identified: Group 1, the Low-Temperature Rising Group (293 patients, 14.69%); Group 2, the Low-Temperature Stable Group (318 patients, 15.94%); Group 3, the Decline-Recovery Group (86 patients, 4.31%); Group 4, the Moderate-Temperature Stable Group (892 patients, 44.71%); and Group 5, the Moderate-Temperature Rising Group (406 patients, 20.35%). Kaplan-Meier analysis showed that patients in Group 1 had the lowest in-hospital and one-year mortality rates. When Group 1 was used as the reference, Group 3 exhibited the highest risk, followed by Group 2, Group 4, and then Group 5. Subgroup analysis showed that the one-year mortality rate was higher in Group 3 patients and remained stable across different complication groups.

Conclusion

Classifying elderly cardiac patients by their perioperative temperature trajectories helps predict all-cause mortality risk. This predictive ability is robust across patients with different comorbidities, enabling personalized treatment strategies.

Trial registration:

Not applicable.

Background

Approximately two million patients undergo cardiac surgery globally each year(1). While advancements in surgical techniques and perioperative care have contributed to a decline in mortality rates(2), they remain elevated compared to other major surgical procedures. Specifically, reported mortality is 2–3% for valve replacement and 4% for coronary artery bypass grafting(3). This risk escalates with more complex or combined operations and in high-risk patients(4, 5).

Body temperature is a vital sign of overall health(6). Conditions like type 2 diabetes and latent infections, often linked to unhealthy lifestyles, are associated with altered thermoregulation and poorer survival. (7, 8). Maintaining normothermia is crucial for normal physiological function(9), which is why it is routinely monitored in clinical settings to assess patient status(6). Temperature is a nonlinear function of multiple variables, including age, health, sex, ambient temperature, and circadian rhythms(10). Notably, hypothermia following cardiac surgery significantly increases the risk of mortality(11, 12), potentially due to systemic failure and resultant peripheral hypoperfusion(13).

Hypothermia triggers peripheral vasoconstriction, which redistributes blood flow by reducing volume to the skin and subcutaneous muscles, thereby minimizing heat loss(14). Under basal conditions, thermogenesis primarily occurs in the liver and heart(15). Decreased pacemaker cell activity leads to bradycardia, and the reduced transmembrane resting potential increases the risk of atrial and ventricular arrhythmias(14). Moderate hypothermia prolongs repolarization and causes arrhythmia(16). Consistent with these functional impairments, evaluations of cardiac biomarkers consistently reveal more significant myocardial damage in patients experiencing hypothermia(17, 18). A critical issue arises during the rewarming phase. While restoring normal temperature is essential for recovery, it can also lead to reperfusion injury(19).

Methods

Data Source

The Medical Information Mart for Intensive Care IV (MIMIC-IV) database (<https://mimic-iv.mit.edu/>) was used to collect the study data. The MIMIC-IV database comprises de-identified clinical data from patients admitted to the Beth Israel Deaconess Medical Center intensive care units between 2008 and 2019. This initiative will not affect clinical care, and the patients in the database cannot be identified; therefore, individual patient consent or ethical approval is not required(20). Research team member Yujie Fan was granted access to the website and was responsible for data collection(ID number: 13908252). This

study adheres to the guidelines of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement(21) and complies with the principles outlined in the Declaration of Helsinki.

LCTM is a sophisticated statistical technique used to identify groups with different trends over time and to explore their characteristics of these trends within individual subgroups(22–24). Typically, two to seven categories can be described, as will be detailed later. At least seven model structures can be fitted(22, 23).

Patients

The inclusion criteria were as follows: First, 8,560 patients were identified based on their surgery dates, the MIMIC-IV database, and International Classification of Diseases (ICD) codes. Cardiac patients undergoing both open-chest surgery and minimally invasive or interventional cardiac procedures. Post-cardiac surgery patients were excluded if they met any of the following criteria: 1) absence of multiple temperature measurements within 72 hours after admission for cardiac surgery, 2) missing survival information, 3) age ≤ 65 years, and 4) postoperative hospital stay < 72 hours.

Observational variables

The primary study variable was the lowest temperature recorded within three days after surgery. Body temperature is recorded as part of routine vital signs. Temperature values were collected within 0–72 hours after surgery. The lowest temperature values during the preceding 24-hour periods were assessed at 24h, 48h, and 72h timepoints. The other variables included: (1) age, gender, and race; (2) The first laboratory values and vital signs within 24 hours after cardiac surgery: INR (International Normalized Ratio), PT (Prothrombin Time), PTT (Partial Thromboplastin Time), Chloride, Bicarbonate, BUN (Blood Urea Nitrogen), Potassium, Creatinine, WBC (White Blood Cell count), MCHC (Mean Corpuscular Hemoglobin Concentration), RDW (Red cell Distribution Width), RBC (Red Blood Cell count), Platelet, MCV (Mean Corpuscular Volume), MCH (Mean Corpuscular Hemoglobin), Hemoglobin, Hematocrit, Lactate, pH, Oxygenation Index ($\text{PaO}_2/\text{FiO}_2$ ratio), PCO_2 (Partial Pressure of Carbon Dioxide), Fibrinogen, Thrombin, Albumin, Calcium, Glucose, heart rate, respiratory rate, systolic blood pressure (SBP), diastolic blood pressure (DBP), and oxygen saturation (SpO_2); (3) Preoperative Comorbidities, including myocardial infarction, malignant tumors, diabetes mellitus, congestive heart failure (CHF), and Cerebrovascular disease (CVD); (4) postoperative supportive therapies, including norepinephrine, dopamine, vasopressin, and continuous renal replacement therapy; (5) extracorporeal circulation auxiliary to open heart surgery(The term 'extracorporeal circulation auxiliary to open heart surgery' was defined as the use of intraoperative cardiopulmonary bypass during the surgical procedure.) (6) outcome variables included in-hospital mortality and all-cause mortality at one year after admission. Navicat Premier 17.0 software and Structured Query Language (SQL) were used to extract metrics from the MIMIC-IV database.

Data processing

Variables with a missing rate exceeding 20% for laboratory measures or covariates were excluded from the analysis. For variables with a missing rate below 20%, multiple imputation was applied to handle missing data. Outliers in body temperature data were corrected using Winsorization.

Statistical analysis

Continuous variables are expressed as the mean $\pm$ standard deviation (SD) or the median and interquartile range (IQR). Categorical variables are reported as numbers and percentages (n (%)). We used the Wilcoxon rank-sum test for continuous variables and the chi-square or Fisher's exact test for categorical variables. Using Kaplan-Meier survival curves, we examined the relationship between temperature trajectories and patient mortality over time. We constructed Cox proportional hazards regression models to evaluate the impact of temperature trajectories on survival outcomes. Three models were developed with progressive adjustment for covariates. Model 1 centered exclusively on the temperature trajectory. Model 2 incorporated adjustments for key demographic factors, namely gender, age, and race. For Model 3, we first conducted univariate screening to identify potential predictors of 1-year survival in older cardiac surgery patients. All covariates significant at $P < 0.05$ in this initial screening—including heart rate, respiratory rate, partial thromboplastin time, platelet count, arterial partial pressure of carbon dioxide, congestive heart failure (CHF), cerebrovascular disease (CVD), and malignant tumor complications—were subsequently incorporated into the final multivariable model alongside the demographic variables from Model 2.

To ascertain the optimal number of classes, a series of models were constructed, ranging from two to seven classes. The evaluation of LCTM fit was conducted by employing log-likelihood, entropy, and information criteria. Lower Akaike and Bayesian information criterion values are indicative of a superior model fit. The entropy value (range: 0–1) is indicative of the model's efficacy in classifying individuals into their respective categories. Typically, an entropy value greater than 0.7 is indicative of high classification accuracy, with higher entropy values corresponding to a superior model fit. To ensure model stability, the sample size for each category should exceed 2% of the total study population. The model's goodness of fit was verified by ensuring that the average posterior probability of all taxonomic members was at least 70%. The clinical interpretability of the model was also taken into consideration.

Results

Trajectory grouping based on the LCTM model

The goodness-of-fit statistics for the LCTM model are displayed in Table 1. The entropy values obtained were all greater than 0.7. The AIC and BIC values exhibited a continuous decrease from the class 1 model to the class 7 model, and the rate of decline demonstrated an inflection point in the class 5 model.

After a thorough evaluation of the available models, the Class 5 model was selected on the basis of its clinical interpretability. Consequently, the fifth class model was regarded as the final model.

Table 1
Fit statistics for different number of trajectory groups.

Number of classes	Log Likelihood	npm	BIC	AIC	Entropy	Relative entropy	%class1	%class2	%class3	%class4	%class5	%class6
1	4120.368	7	8293.926	8254.74	1	1	100					
2	3754.774	12	7600.728	7533.547	403.614	0.708	45.81454	54.18546				
3	3495.889	17	7120.951	7025.779	513.764	0.766	11.17794	37.29323	51.52882			
4	3364.738	22	6896.64	6773.476	817.967	0.704	30.97744	23.40852	41.30326	4.310777		
5	3261.206	27	6727.569	6576.412	891.245	0.722	14.68672	15.93985	4.310777	44.71178	20.35088	
6	3225.815	32	6694.779	6515.63	956.597	0.732	13.13283	14.98747	21.75439	5.413534	40.30075	4.411028
7	3194.61	37	6670.361	6463.221	1132.62	0.708	6.115288	12.98246	22.80702	2.857143	10.62657	38.64662

Log Likelihood: Logarithm of the likelihood function; npm: number of free parameters; BIC: Bayesian Information Criterion; AIC: Akaike Information Criterion.

The temperature trajectories of the five models are shown in Fig. 1. LCTM-5 classified the development cohort into five categories: class 1 [293 (14.69%)];

class 2 [318 (15.94%)];

class 3 [86 (4.31%)];

class 4 [892 (44.71%)];

and class 5 [406 (20.35%)]. In Class 1, the initial lowest temperature was below 35°C, followed by a rewarming period. The Class 2 is the low-grade stable group, whose lowest temperature remained at approximately 35.9°C. The Class 3 is the decline-recovery Group, which is characterized by an initial lowest temperature below 36°C, followed by a process of first decreasing and then rebounding. In the Class 4 of moderate-temperature stable groups, the lowest recorded temperature was maintained at a moderate level of approximately 36.4°C. In Class 5, the lowest temperature in moderate temperature rise groups commenced from a comparatively modest initial value and ascended to approximately 36.5°C, exhibiting a persistent upward tendency.

Characteristics of temperature trajectories

The initial sample size for the study was determined to be 8,560 patients. Following the application of inclusion and exclusion criteria, a total of 1,995 patients were ultimately enrolled in the study. Figure 2 depicts the patient inclusion and exclusion flowchart. The baseline characteristics of patients stratified based on the five trajectory classes are listed in Table 3. Most of the patients were male (1,255, or 62.9%) and white (1,542, or 77.3%). Of the study subjects, 595 (29.8%) had a history of myocardial infarction; 712 (35.7%) were identified as having congestive heart failure (CHF); 276 (13.8%) were diagnosed with chronic kidney disease (CKD); 496 (24.9%) had been diagnosed with chronic lung disease; and 747 (37.4%) had been diagnosed with diabetes mellitus. Meanwhile, 63 patients (3.2%) underwent continuous renal replacement therapy, 133 patients (6.7%) used vasopressin, 359 patients (18%) used norepinephrine during hospitalization, and 526 patients (26.4%) underwent cardiac surgery using extracorporeal circulation auxiliary to open heart surgery.

Table 3
Descriptive characteristics of overall participants and by temperature trajectory

Variables	level	Overall(n = 1995)	Group1(n = 293)	Group2(n = 318)	Group3(n = 86)	Group4(n = 892)
Gender	Female	740(37.1)	141(48.1)	130(40.9)	36(41.9)	289(32.4)
	Male	1255(62.9)	152(51.9)	188(59.1)	50(58.1)	603(67.6)
Age(years)		76.81(7.33)	77.70(7.20)	77.74(7.40)	76.92(6.55)	76.16(7.51)
Race	Other	453(22.7)	74(25.3)	49(15.4)	17(19.8)	207(23.2)
	White	1542(77.3)	219(74.7)	269(84.6)	69(80.2)	685(76.8)
Weight		80.00(68.60,92.90)	75.20(63.50,87.00)	80.00(66.93,93.38)	79.35(67.05,88.90)	81.70(70.00,94.85)
Height		170.00(160.00,176.50)	168.00(160.00,173.00)	168.00(160.00,175.00)	168.00(160.00,175.00)	170.00(163.00,178.0)
Heart rate		80.00(73.00,85.00)	80.00(72.00,85.00)	80.00(75.00,87.75)	80.00(75.00,89.50)	80.00(71.00,85.00)
Sbp		112.00(100.00,126.00)	113.00(100.00,124.00)	110.00(98.25,123.00)	108.00(98.00,118.00)	115.00(102.00,129.0
Dbp		55.00(49.00,63.00)	57.00(50.00,65.00)	55.00(49.00,61.00)	54.00(46.00,60.88)	55.00(49.00,63.00)
Resp rate		15.00(14.00,17.00)	15.00(14.00,16.00)	14.00(13.00,16.00)	15.00(14.00,16.00)	16.00(14.00,18.00)
SpO ₂		100.00(99.00,100.00)	100.00(100.00,100.00)	100.00(99.00,100.00)	100.00(99.00,100.00)	100.00(98.00,100.00)
Inr		1.30(1.20,1.50)	1.40(1.20,1.60)	1.30(1.20,1.50)	1.30(1.10,1.40)	1.30(1.20,1.50)
Pt		14.80(13.10,16.40)	15.20(13.60,16.90)	14.80(13.50,16.17)	14.40(13.12,15.85)	14.40(12.70,16.22)
Ptt		33.90(29.30,51.00)	35.20(30.10,51.50)	34.85(29.50,52.02)	34.10(28.50,54.15)	33.55(28.90,53.95)
Chloride		107.00(104.00,110.00)	109.00(105.00,112.00)	108.00(103.00,111.00)	106.00(103.00,111.00)	107.00(103.00,109.0
Bicarbonate		23.00(22.00,25.00)	23.00(21.00,25.00)	24.00(22.00,26.00)	24.00(23.00,26.00)	24.00(22.00,26.00)
Bun		18.00(14.00,25.00)	18.00(13.00,23.00)	20.00(15.00,28.00)	19.00(15.00,25.50)	18.00(14.00,25.00)
Potassium		4.20(3.90,4.50)	4.20(3.90,4.50)	4.30(3.90,4.60)	4.20(3.90,4.60)	4.20(3.90,4.60)
Creatinine		0.90(0.70,1.20)	0.80(0.70,1.10)	1.00(0.80,1.20)	1.00(0.72,1.30)	0.90(0.70,1.20)
Wbc		9.70(7.40,13.20)	9.60(7.00,12.70)	9.60(7.30,12.78)	10.05(8.22,12.60)	9.75(7.30,13.43)
Mchc		33.20(32.20,34.10)	33.20(32.30,33.90)	33.60(32.50,34.40)	33.60(32.32,34.70)	33.00(32.10,33.90)
Rdw		13.80(13.10,14.90)	13.80(13.10,14.70)	14.05(13.33,15.30)	14.20(13.70,15.20)	13.70(13.00,14.90)
Rbc		3.19(2.76,3.68)	3.08(2.60,3.59)	3.09(2.69,3.65)	3.24(2.82,3.83)	3.30(2.86,3.77)
Platelet		152.00(119.00,197.00)	136.00(107.00,183.00)	160.00(126.25,212.75)	174.00(128.75,218.00)	156.50(124.00,201.0
Mcv		91.00(88.00,95.00)	92.00(88.00,95.00)	90.00(87.00,93.00)	90.00(87.00,93.00)	92.00(88.00,95.00)
Hemoglobin		9.60(8.30,11.00)	9.30(8.00,10.80)	9.20(8.00,11.00)	9.65(8.33,11.28)	9.90(8.60,11.22)
Hematocrit		29.00(25.20,33.50)	28.30(24.30,32.70)	27.65(24.52,32.50)	28.85(25.20,34.30)	29.90(26.50,34.30)
Lactate		1.30(1.00,1.70)	1.30(1.00,1.80)	1.20(0.90,1.60)	1.20(1.00,1.67)	1.35(1.00,1.80)
Sbp, Systolic blood pressure; Dbp, Diastolic blood pressure; SpO ₂ , Oxygen saturation; Inr, International normalized ratio; Pt, Prothrombin time; Ptt, Partial thrombocyte count; Mchc, Mean corpuscular hemoglobin concentration						

Variables	level	Overall(n = 1995)	Group1(n = 293)	Group2(n = 318)	Group3(n = 86)	Group4(n = 892)
Gender	Female	740(37.1)	141(48.1)	130(40.9)	36(41.9)	289(32.4)
	Male	1255(62.9)	152(51.9)	188(59.1)	50(58.1)	603(67.6)
PH		7.41(7.38,7.44)	7.41(7.38,7.45)	7.41(7.38,7.44)	7.42(7.39,7.46)	7.40(7.37,7.43)
oxygenation index		277.00(188.00,369.00)	311.00(221.00,393.00)	277.50(194.50,367.00)	265.00(191.00,331.75)	265.50(176.00,358.00)
PCO ₂		40.00(37.00,44.00)	39.00(36.00,43.00)	41.00(37.00,45.00)	38.00(35.25,42.00)	41.00(37.00,45.00)
Dopamine used	No	1943(97.4)	289(98.6)	306(96.2)	83(96.5)	866(97.1)
	Yes	52(2.6)	4(1.4)	12(3.8)	3(3.5)	26(2.9)
Vasopressin used	No	1862(93.3)	272(92.8)	292(91.8)	75(87.2)	847(95.0)
	Yes	133(6.7)	21(7.2)	26(8.2)	11(12.8)	45(5.0)
CRRT	No	1932(96.8)	285(97.3)	303(95.3)	78(90.7)	873(97.9)
	Yes	63(3.2)	8(2.7)	15(4.7)	8(9.3)	19(2.1)
Delirium	No	1662(83.3)	237(80.9)	280(88.1)	70(81.4)	741(83.1)
	Yes	333(16.7)	56(19.1)	38(11.9)	16(18.6)	151(16.9)
Myocardial Infarct	No	1400(70.2)	226(77.1)	210(66.0)	59(68.6)	624(70.0)
	Yes	595(29.8)	67(22.9)	108(34.0)	27(31.4)	268(30.0)
Congestive Heart failure	No	1283(64.3)	212(72.4)	177(55.7)	54(62.8)	572(64.1)
	Yes	712(35.7)	81(27.6)	141(44.3)	32(37.2)	320(35.9)
Peripheral Vascular disease	No	1639(82.2)	228(77.8)	259(81.4)	68(79.1)	739(82.8)
	Yes	356(17.8)	65(22.2)	59(18.6)	18(20.9)	153(17.2)
CVD	No	1719(86.2)	256(87.4)	265(83.3)	73(84.9)	775(86.9)
	Yes	276(13.8)	37(12.6)	53(16.7)	13(15.1)	117(13.1)
Dementia	No	1967(98.6)	291(99.3)	315(99.1)	85(98.8)	875(98.1)
	Yes	28(1.4)	2(0.7)	3(0.9)	1(1.2)	17(1.9)
Chronic pulmonary disease	No	1499(75.1)	225(76.8)	225(70.8)	71(82.6)	671(75.2)
	Yes	496(24.9)	68(23.2)	93(29.2)	15(17.4)	221(24.8)
Rheumatic Disease	No	1902(95.3)	275(93.9)	307(96.5)	82(95.3)	851(95.4)
	Yes	93(4.7)	18(6.1)	11(3.5)	4(4.7)	41(4.6)
Sbp, Systolic blood pressure; Dbp, Diastolic blood pressure; SpO2, Oxygen saturation; Inr, International normalized ratio; Pt, Prothrombin time; Ptt, Partial thromboplastin time; Mchc, Mean corpuscular hemoglobin concentration						

Variables	level	Overall(n = 1995)	Group1(n = 293)	Group2(n = 318)	Group3(n = 86)	Group4(n = 892)
Gender	Female	740(37.1)	141(48.1)	130(40.9)	36(41.9)	289(32.4)
	Male	1255(62.9)	152(51.9)	188(59.1)	50(58.1)	603(67.6)
Peptic ulcer						
Disease	No	1983(99.4)	289(98.6)	316(99.4)	85(98.8)	890(99.8)
	Yes	12(0.6)	4(1.4)	2(0.6)	1(1.2)	2(0.2)
Mild liver						
disease	No	1934(96.9)	291(99.3)	310(97.5)	83(96.5)	861(96.5)
	Yes	61(3.1)	2(0.7)	8(2.5)	3(3.5)	31(3.5)
Diabetes						
	No	1248(62.6)	208(71.0)	197(61.9)	52(60.5)	526(59.0)
	Yes	747(37.4)	85(29.0)	121(38.1)	34(39.5)	366(41.0)
Diabetes						
mellitus	No	1434(71.9)	226(77.1)	230(72.3)	58(67.4)	621(69.6)
without	Yes	561(28.1)	67(22.9)	88(27.7)	28(32.6)	271(30.4)
complications						
Diabetes						
mellitus	No	1758(88.1)	268(91.5)	277(87.1)	78(90.7)	774(86.8)
with	Yes	237(11.9)	25(8.5)	41(12.9)	8(9.3)	118(13.2)
complications						
Paraplegia						
	No	1962(98.3)	289(98.6)	313(98.4)	85(98.8)	875(98.1)
	Yes	33(1.7)	4(1.4)	5(1.6)	1(1.2)	17(1.9)
Renal disease						
	No	1489(74.6)	221(75.4)	226(71.1)	66(76.7)	669(75.0)
	Yes	506(25.4)	72(24.6)	92(28.9)	20(23.3)	223(25.0)
Malignant						
cancer	No	1915(96.0)	280(95.6)	305(95.9)	86(100.0)	855(95.9)
	Yes	80(4.0)	13(4.4)	13(4.1)	0(0.0)	37(4.1)
Severe liver						
disease	No	1985(99.5)	293(100.0)	315(99.1)	86(100.0)	886(99.3)
	Yes	10(0.5)	0(0.0)	3(0.9)	0(0.0)	6(0.7)
Metastatic						
solid tumor	No	1985(99.5)	292(99.7)	316(99.4)	86(100.0)	886(99.3)
	Yes	10(0.5)	1(0.3)	2(0.6)	0(0.0)	6(0.7)
Extracorporeal						
circulation						
Auxiliary to	No	1469(73.6)	206(70.3)	180(56.6)	50(58.1)	732(82.1)
Open heart	Yes	526(26.4)	87(29.7)	138(43.4)	36(41.9)	160(17.9)
surgery						
Norepinephrine						
used	No	1636(82.0)	236(80.5)	257(80.8)	59(68.6)	742(83.2)
	Yes	359(18.0)	57(19.5)	61(19.2)	27(31.4)	150(16.8)
Sbp, Systolic blood pressure; Dbp, Diastolic blood pressure; SpO2, Oxygen saturation; Inr, International normalized ratio; Pt, Prothrombin time; Ptt, Partial thromboplastin time; Mchc, Mean corpuscular hemoglobin concentration						

Table 3 about here.

Compared to the other groups, Class 1 exhibited lower creatinine levels. A comparative analysis revealed that Class 3 had lower systolic blood pressure, chloride levels, mean corpuscular hemoglobin, and oxygenation index than the other groups. Conversely, the white blood cell count, red blood cell distribution width, platelet count, blood pH, proportion of patients using vasopressin and norepinephrine, proportion of patients with and without diabetic complications, and proportion of patients receiving continuous renal replacement therapy (CRRT) were higher. The Table 3 illustrates the fundamental characteristics of the aforementioned five classes.

Univariate and multivariate analysis

Figure 3 illustrates the Kaplan-Meier survival curves of disparate temperature trajectory groups at one year. The one-year mortality rate was found to be the lowest in Class 1, while Class 3 exhibited the highest rate.

Table 2 shows the baseline characteristics of one-year survivors and non-survivors. Variables with a significance level of $p < 0.05$ in univariate analysis were included as covariates in the multivariate Cox proportional hazards model (Model 3).

Table 2
Baseline characteristics of the Survivors and Non-survivors

Variables		Overall	Survival	Non-survivors	p
N		1995	1818	177	
Gender	Female	740(37.1)	665(36.6)	75(42.4)	0.149
	Male	1255(62.9)	1153(63.4)	102(57.6)	
Age(years)		76.81(7.33)	76.43(7.16)	80.74(7.87)	< 0.001
Race	Other	453(22.7)	415(22.8)	38(21.5)	0.751
	White	1542(77.3)	1403(77.2)	139(78.5)	
Heart rate		79.18(11.46)	78.81(11.13)	82.95(13.93)	< 0.001
Sbp		114.53(20.85)	114.37(20.49)	116.26(24.26)	0.25
Dbp		56.38(11.44)	56.47(11.25)	55.47(13.30)	0.268
Resp rate		15.61(4.01)	15.50(3.88)	16.83(5.00)	< 0.001
Hemoglobin		9.84(1.99)	9.85(2.01)	9.70(1.81)	0.323
Creatinine		1.11(0.88)	1.08(0.84)	1.48(1.15)	< 0.001
Potassium		4.25(0.52)	4.25(0.52)	4.26(0.59)	0.723
Pt		15.21(5.09)	15.17(5.11)	15.71(4.86)	0.174
Ptt		44.94(26.84)	43.94(25.67)	55.22(35.31)	< 0.001
Rbc		3.27(0.69)	3.27(0.69)	3.28(0.64)	0.807
Platelet		165.69(68.29)	164.00(66.62)	183.10(81.66)	< 0.001
Wbc		10.98(5.86)	11.02(5.89)	10.65(5.50)	0.423
Lactate		1.45(1.04)	1.45(1.05)	1.47(0.91)	0.82
PH		7.41(0.05)	7.41(0.05)	7.40(0.07)	0.169
PCO2		40.72(6.06)	40.58(5.85)	42.18(7.77)	0.001
CHF	No	1283(64.3)	1229(67.6)	54(30.5)	< 0.001
	Yes	712(35.7)	589(32.4)	123(69.5)	
Myocardial infarct	No	1400(70.2)	1284(70.6)	116(65.5)	0.184
	Yes	595(29.8)	534(29.4)	61(34.5)	
CVD	No	1719(86.2)	1580(86.9)	139(78.5)	0.003
	Yes	276(13.8)	238(13.1)	38(21.5)	
Malignant cancer	No	1915(96.0)	1752(96.4)	163(92.1)	0.01
	Yes	80(4.0)	66(3.6)	14(7.9)	
Diabetes	No	1248(62.6)	1135(62.4)	113(63.8)	0.773
	Yes	747(37.4)	683(37.6)	64(36.2)	
Extracorporeal circulation Auxiliary to Open heart surgery	No	1469(73.6)	1328(73.0)	141(79.7)	0.069
	Yes	526(26.4)	490(27.0)	36(20.3)	

Sbp, Systolic blood pressure; Dbp, Diastolic blood pressure; Pt, Prothrombin time; Ptt, Partial thromboplastin time; Rbc, Red blood cell count; Wbc, White blood cell count; PH, potential of hydrogen in blood; Pco2, Partial pressure of carbon dioxide.

Figure 4 shows the final results of three models, each of which focuses on one-year and in-hospital patient mortality. Models 1–3 were derived from multivariable Cox regression models. Model 1 centered exclusively on the temperature trajectory. Model 2 incorporated adjustments for key demographic factors, namely gender, age, and race. The Model 3 covariates were adjusted for the following: sex, age, race, heart rate, respiratory rate, partial thromboplastin time, platelet count, arterial partial pressure of carbon dioxide, CHF, CVD, and malignant tumor complications. In the analysis employing

Class 1 temperature trajectories as the reference, patients with Class 3 temperature trajectories had the highest risk. Subsequent to the implementation of comprehensive adjustments to account for the presence of various confounders, the initial trend remained consistent.

Subgroup analyses

Stratified subgroup analyses were performed based on the following variables: key demographic factors (gender, age, and race), and congestive heart failure, cerebrovascular disease, and diabetes, which were identified as significant predictors of one-year mortality in our univariate analysis. Figure 5 shows the forest plot of the patient subgroup analysis. Patients on trajectory 3 had a higher one-year mortality rate, while patients on trajectory 1 had the lowest rate. This remained stable across different age groups and patients with various underlying conditions.

Discussion

We describe a framework for deriving subphenotypes in cardiac-surgery patients from post-operative temperature trajectories. Using group-based trajectory modelling, we identified and validated five distinct temperature-profile clusters. These clusters differed markedly in baseline demographics, physiology, and mortality. With cluster 1 as reference, mortality risk was highest in cluster 3, followed by clusters 2, 4, and 5. The elevated one-year mortality observed in cluster 3 remained consistent across all complication subgroups. Subsequent analyses revealed significant inter-cluster differences in age, race, heart rate, respiratory rate, partial thromboplastin time, platelet count, arterial PCO₂, and prevalence of congestive heart failure, cerebrovascular disease, and malignant tumours. Our findings underscore the heterogeneity of older adults after cardiac surgery and provide a foundation for precision-oriented research. Subphenotype identification may facilitate tailored management strategies(25). Longitudinal temperature data are universally available and can serve as an accessible ancillary tool for detecting clinically relevant post-operative cardiac conditions. By applying latent-class trajectory modelling to three-day temperature profiles—minimising bias inherent in single-point measurements—we generated stable, reproducible insights to guide clinical care in elderly cardiac patients.

At the cellular level, low temperatures inhibit enzymatic activity and reduce ATP production(19). The body triggers peripheral vasoconstriction to conserve heat, redirecting blood flow. This compensatory mechanism, however, elevates systemic vascular resistance and decreases cardiac output, ultimately compromising coronary and peripheral perfusion. The resultant reduction in blood flow exacerbates pre-existing metabolic acidosis and myocardial ischemia(19).

Compared to single time-point measurements, which are susceptible to bias(26), temperature trajectories offer a more accurate representation of a patient's physiological state. Temperature fluctuations can precipitate acute cardiovascular events(27). The rewarming phase following hypothermia is particularly hazardous due to a surge in oxygen demand, which may induce myocardial ischemia(28). Regarding the effect of drugs on temperature, one study showed that acetaminophen administration did not significantly affect temperature trajectories(29). The white blood cell count of class 3 was higher than that of the other groups. Thermoregulation is closely related to the immune system(30, 31). Hypothermia can produce significant physiological changes, such as a left shift in the oxygenation curve, decreased coagulation function, and arrhythmia. These changes may lead to tissue hypoxia, multiple organ dysfunction, and fluid resuscitation failure(32). These adverse outcomes, encompassing bleeding, infection, and renal failure, are well-documented(19, 33). Coagulopathy results from altered steady-state enzymatic activity of coagulation factors(14, 34).

Advanced age is a significant prognostic factor in surgical patients(35). Physiologically, elderly individuals possess diminished thermoregulatory capacity due to lower subcutaneous fat, a reduced basal metabolic rate, and declining central nervous system function, rendering them highly susceptible to inadvertent hypothermia(6, 36). This vulnerability carries profound clinical implications, as being over 80 years old is an independent predictor of 30-day mortality after aortic valve replacement and adversely impacts long-term survival(37). Similarly, diabetes mellitus is associated with elevated perioperative complications, increased in-hospital mortality, and reduced long-term survival following cardiac surgery(38, 39).

Lower creatinine levels were observed in patients with a more favorable prognosis(40), a finding potentially attributable to early aggressive fluid resuscitation that mitigates renal hypoperfusion and preserves glomerular filtration(41). Furthermore, the observed sex-based disparity in creatinine levels—with a higher proportion of males in the high-creatinine group—suggests a influence of sex hormones, whereby testosterone may increase and estradiol may decrease creatinine production(42). In contrast to the prognostic value of creatinine, our results align with previous studies indicating that cardiopulmonary bypass time did not exhibit a statistically significant association with prognosis(37, 40). Regarding perioperative temperature management, although intentional hypothermia is routinely employed during cardiopulmonary bypass, active rewarming before weaning from bypass may explain the lower incidence of postoperative hypothermia following cardiac compared to non-cardiac surgery(43).

We developed predictive models for in-hospital and one-year mortality, identifying several general patient characteristics as key risk factors, including sex, age, race, vital signs (heart rate, respiratory rate), laboratory parameters (partial thromboplastin time, platelet count, PaCO₂), and comorbidities (CHF, CVD, malignancy). The inclusion of sex is supported by physiological studies indicating that women, on average, have a higher percentage of subcutaneous body fat and lower mean skin temperatures, differences potentially mediated by female hormone levels(44, 45). Advanced age is a well-established risk factor, as older patients exhibit a higher prevalence of preoperative complications like CHF(37). The model also corroborates known clinical risks, such as the association between diabetes and increased perioperative complications, higher in-hospital mortality, and reduced long-term survival after cardiac surgery(38, 39). Furthermore, the relevance of platelet count is underscored by the pathophysiological link between hypothermia and coagulopathy; even mild core temperature drops of 1–2°C can reversibly impair platelet aggregation by reducing thromboxane A₃ production and disrupting platelet formation(19, 46).

The findings of this study could aid in the early identification of high-risk patients following cardiac surgery, enabling timely interventions to reduce disease burden and mortality. Furthermore, the utilization of real-world data ensured a large sample size with substantial ethnic diversity. Temperature, as an intuitive,

readily available, and cost-effective indicator, offers a practical advantage over many laboratory parameters.

This study is the first to investigate long-term temperature patterns in patients undergoing cardiac surgery, identifying five distinct patient subgroups based on their temperature trajectories. Our analysis revealed a previously unreported high-risk subgroup. However, this study has several limitations. First, its retrospective, single-center design inevitably introduces selection bias, and the exclusion of patients with missing data constitutes a significant limitation. Furthermore, as all dates were subjected to a random offset process for privacy protection, the specific annual case distribution cannot be provided. Finally, body temperature is regulated by a multitude of factors, not all of which could be accounted for in this study; whether these factors dynamically influence temperature trajectories warrants further investigation. Despite these limitations, we have successfully enhanced the understanding of post-cardiac surgery pathophysiology by identifying a unique patient subgroup with distinctive clinical features and significantly different outcomes. This study provides valuable insights into cardiac surgery prognosis and paves the way for future research aimed at predicting and treating early postoperative patient subphenotypes.

Conclusions

We identified five robust and clinically distinct temperature trajectory subgroups among elderly patients following cardiac surgery, which were significantly associated with both in-hospital and long-term mortality. Notably, the subgroup with the highest mortality risk exhibited an initial minimum temperature below 36°C, followed by a subsequent decline and eventual rebound. Conversely, the subgroup with the most favorable prognosis demonstrated rapid rewarming after an initial minimum temperature below 35°C. This critical distinction, which would be overlooked in studies relying on single time-point measurements, underscores the prognostic value of dynamic temperature monitoring. Our findings demonstrate that temperature trajectories can effectively identify unique patient subphenotypes, thereby paving the way for personalized management strategies in post-cardiac surgery care.

Abbreviations

LCTM
Latent Class Trajectory Model
ICD
International Classification of Diseases
SD
Standard deviation
IQR
Interquartile range
CRRT
Continuous renal replacement therapy
CABG
Coronary artery bypass graft
PaCO₂
Arterial partial pressure of carbon dioxide
MIMIC-IV
Medical Information Mart for Intensive Care-IV
CHF
Congestive heart failure
CVD
Cerebrovascular disease

Declarations

Ethics approval and consent to participate

The model was developed and validated based on public database. After completing the Collaborative Institutional Training Initiative programme, we got permission to access the database. This study used public deidentification databases, so there is no need to obtain the informed consent and approval of the Institutional Review Board. Participants gave informed consent to participate in the study before taking part.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analysed during the current study are available in the [Medical Information Mart for Intensive Care (MIMIC)-IV] repository, [<https://mimic.mit.edu/docs/iv/>].

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Yujie Fan played a key role in collecting and analyzing the data, and in drafting the manuscript. Hao Yuan and Zefeng Yang played a pivotal role in extracting the data and designing the study. Jiayao Wei and Longteng Nan revised the manuscript for intellectual content. Qiang Li oversaw the entire project, providing guidance and contributing to the study's design and review. All authors read and approved the final manuscript.

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Figures

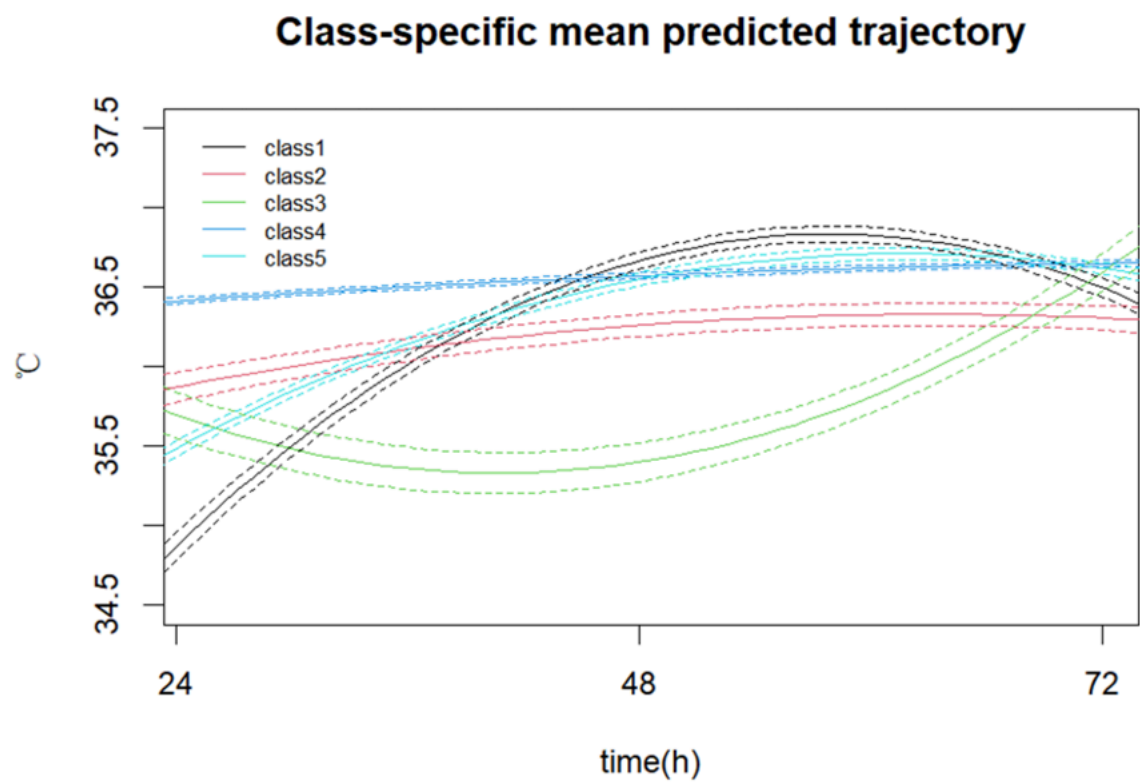


Figure 1

Five trajectories of body temperature based on LCTM. The dotted lines indicate the 95% confidence interval for each trajectory.

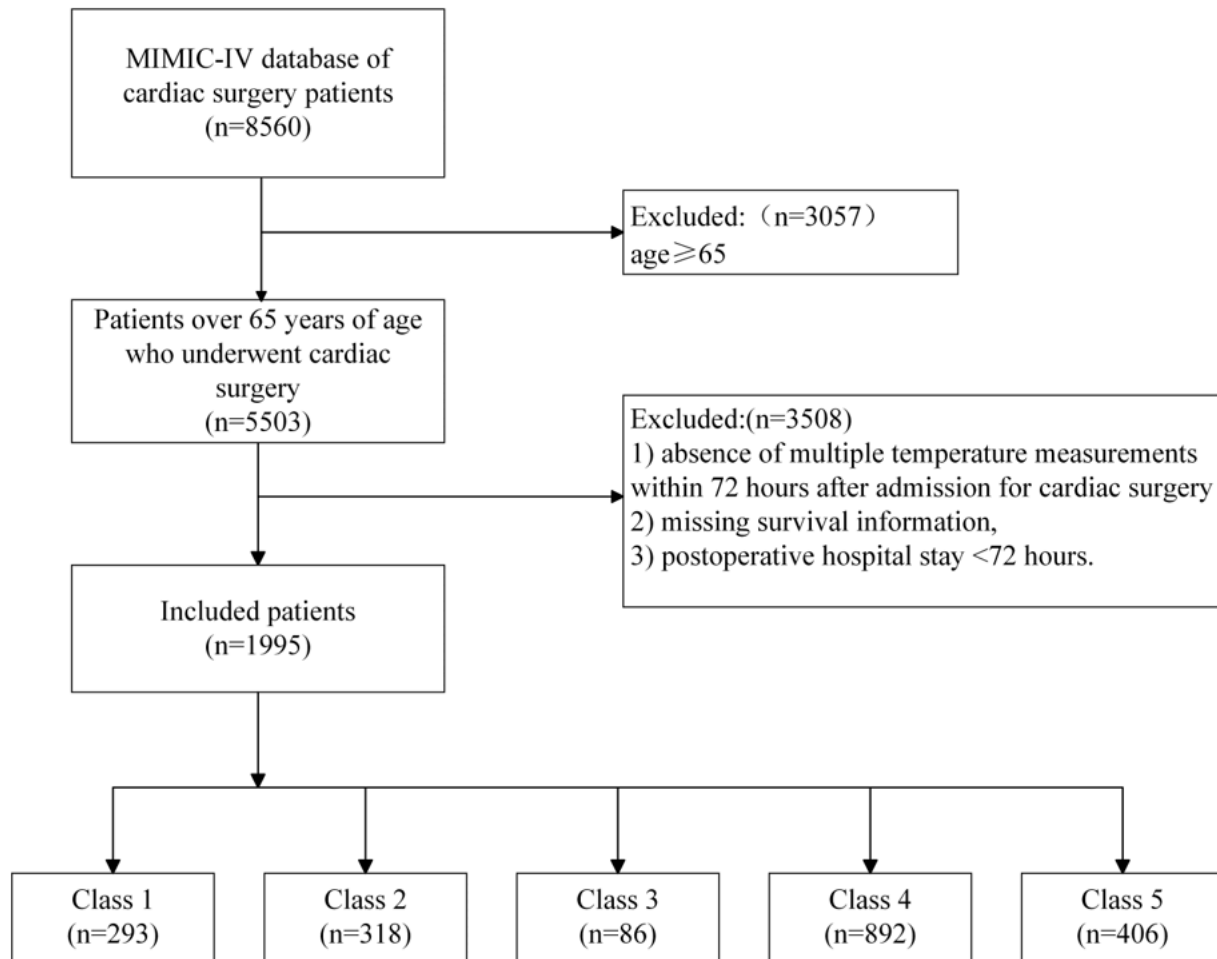


Figure 2

Inclusion and exclusion criteria

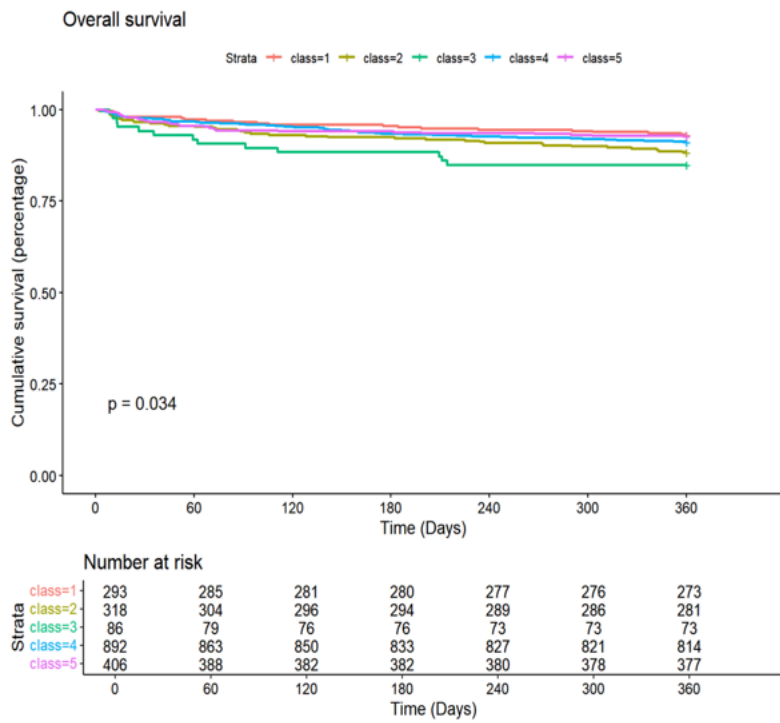


Figure 3

The one-year survival curves were generated using the Kaplan-Meier method.

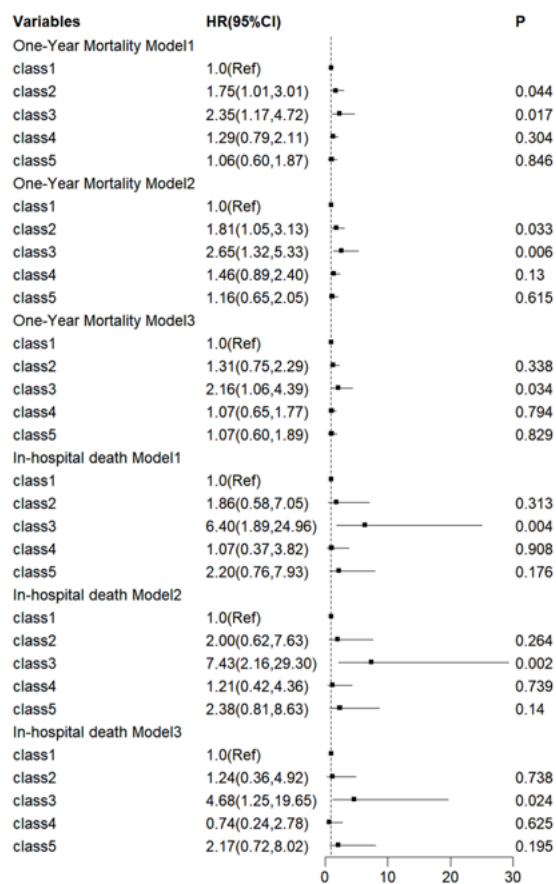


Figure 4

Multivariate COX analysis was performed using logistic regression analysis to identify risk factors for in-hospital death and 1-year mortality in patients.

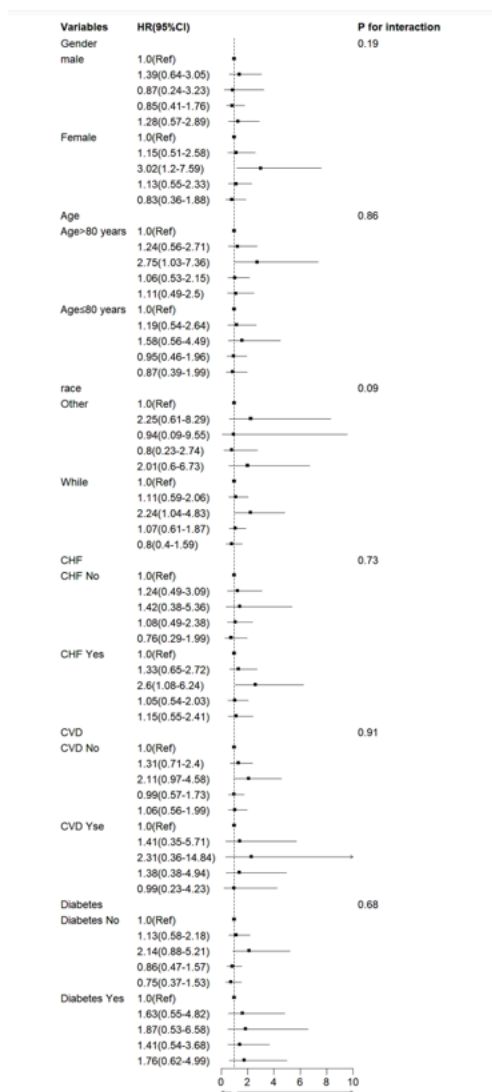


Figure 5

Subgroup analysis using forest plots was performed to explore the relationship between one-year mortality and body temperature trajectories. CHF: congestive heart failure, CVD: Cerebrovascular disease.