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Article

Effect of Hot Climate on Bleeding Tendency After Cardiac Surgery in Egyptian Patients

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Abstract

Background: Postoperative bleeding remains a significant cause of morbidity following cardiac surgery with cardiopulmonary bypass (CPB). Climatic and environmental conditions can influence coagulation dynamics, platelet function, and vascular responses. Thus, this study aimed to assess the effect of regional climatic differences on postoperative bleeding in Egyptian patients undergoing cardiac surgery with CPB. **Methods:** This retrospective observational study included 400 Egyptian patients, aged ≥18 years, of both sexes, who underwent open-heart surgery with CPB. Patients were equally categorized, by residence and surgical center, into a hot-climate group from Upper Egypt and a moderate- to lower-temperature-climate group from Lower Egypt. Regional climatic classification was supported by published climatological data on average temperature, summer temperature profile, humidity, and aridity. Demographic, clinical, coagulation, bleeding, transfusion, re-exploration, mortality, operative, temperature management, anticoagulation, antifibrinolytic, and hemostatic variables were analyzed. A STROBE-compliant patient flow diagram was used to depict screening, exclusion, and final enrollment by surgical subtype. **Results:** Bleeding time (BT) and the associated changes were significantly higher in the hot-climate group than in the cold group both preoperatively and postoperatively ($p < 0.001$). Platelet function (PF) and the associated changes were significantly reduced in the hot-climate group at both time points ($p < 0.001$). Prothrombin time (PT), activated partial thromboplastin time (aPTT), international normalized ratio (INR), and their respective changes were comparable between groups. Postoperative fibrinogen levels were significantly higher in the hot-climate group ($p = 0.05$). Total bleeding volume, transfusion requirements, and re-exploration incidence were significantly higher in the hot group. After multivariable adjustment for climate group, demographic variables, comorbidities, procedure type, CPB duration, aortic cross-clamp time, temperature-management variables, heparin/activated clotting time (ACT)/protamine variables, tranexamic acid use, and hemostatic-agent use, residence in a hot-climate region remained independently associated with higher 24-hour bleeding volume. **Conclusions:** Regional environmental factors were associated with perioperative hemostasis and bleeding outcomes in cardiac surgery with CPB. Patients from hot-climate regions showed higher postoperative bleeding, greater transfusion requirements, and increased re-exploration rates. These findings support adding preoperative platelet function testing, where available, into standard coagulation assessment for patients from hot-climate regions, together with standardized antifibrinolytic use and enhanced surveillance for postoperative bleeding during the first 24 hours after surgery.

Keywords: climate effect; cardiopulmonary bypass; bleeding; Egypt

1. Introduction

Egypt experiences extremely high ambient temperatures, especially during the summer months, with daily highs frequently exceeding 40 °C. Such climatic extremes can influence physiological homeostasis in surgical patients by altering fluid balance, cardiovascular strain, and hemostatic function. In cardiac surgery, where bleeding complications are a significant cause of morbidity and mortality, the role of environmental temperature in modulating perioperative bleeding risk is an underexplored but potentially critical factor in patient outcomes [1,2].

Body temperature influences multiple aspects of coagulation. Hyperthermia and dehydration, common in hot climates, may increase blood viscosity and it, potentially predisposing to thrombosis. However, heat stress can also impair platelet aggregation and alter clotting factor activity, leading to increased bleeding risk. These changes are mediated by fluid shifts, endothelial responses, and altered enzymatic activity in the coagulation cascade [3].

Cardiac surgery, particularly procedures involving cardiopulmonary bypass (CPB), is associa with complex coagulation disturbances due to hemodilution, platelet activation, platelet dysfunction, inflammatory responses, and temperature-related alterations in enzymatic coagulation. Studies have shown that maintaining normothermic CPB (35–37 °C) results in less postoperative blood loss and better platelet preservation compared with hypothermic CPB (25–29 °C), but the effects of preoperative environmental heat exposure on intraoperative and postoperative bleeding remain poorly defined [4,5].

Seasonal and climatic variations have been linked to changes in cardiovascular surgical outcomes, including mortality, length of stay, and complication rates. Several large observational studies have noted increased bleeding or transfusion requirements in surgeries performed under certain environmental conditions, though findings remain inconsistent [6,7].

This environmental exposure may interact with CPB-induced coagulopathy to worsen postoperative bleeding, necessitating greater transfusion volumes and potentially prolonging hospital stay [6]. Egypt has diverse climatic zones, with Upper Egypt being hotter and more arid than Lower Egypt. While the impact of climate on health has been studied globally, its effect on surgical outcomes, particularly postoperative bleeding in cardiac surgery, remains unclear in Egypt. Given the absence of local data and the plausible pathophysiological links between regional climatic conditions and bleeding risk, this study aimed to compare postoperative bleeding outcomes in cardiac surgery patients from hot-climate zones of Upper Egypt with those from moderate/lower-temperature zones of Lower Egypt. The study sought to explore whether residence in a hot-climate area is associated with increased bleeding tendency after cardiac surgery in Egyptian patients [8].

This work assessed the effect of regional climatic differences on postoperative bleeding in Egyptian patients undergoing cardiac surgery with cardiopulmonary bypass, by comparing outcomes between patients from hot climate zones (Upper Egypt) and those from moderate climate zones (Lower Egypt).

2. Materials and Methods

This retrospective observational study involved 400 Egyptian patients of both sexes, aged ≥18 years, who underwent open-heart surgery with cardiopulmonary bypass. The study covered a two-year period between June 2023 and June 2025, following approval from the ethical committee of Al-Azhar University Hospitals, Cairo, Egypt, with written informed consent obtained according to institutional requirements.

Patients were categorized into two groups according to residence and surgical center location. Group A (Hot Climate Group) included patients from Upper Egypt who underwent surgery at Tiba Specialized Hospital serving the Luxor, Qena, and Aswan regions. Group B (Moderate/Lower-Temperature Climate Group) included patients from Lower Egypt who underwent surgery at Al-Azhar University Hospitals in Cairo.

To reduce center-related heterogeneity, most procedures in both centers were performed by the same or overlapping surgical team using comparable operative techniques. This allowed comparison of cases performed by the same team in the university hospital setting with cases performed by the same team within the comprehensive health insurance sector. The two participating centers were Al-Azhar University Hospitals in Lower Egypt and Tiba Specialized Hospital, part of the Luxor sector of the Egypt Healthcare Authority, in Upper Egypt.

Exclusion criteria included incomplete medical records or missing postoperative bleeding data, emergency surgeries, pre-existing coagulopathy, use of anticoagulants not discontinued prior to surgery, and re-do surgeries.

Climate exposure classification was based on residence and surgical center location and was supported by published climatological records. Upper Egypt was categorized as the hot-climate zone because Luxor and Aswan have higher mean annual temperatures, minimal annual precipitation, and summer high temperatures commonly around 39–41 °C. Lower Egypt/Cairo was categorized as the moderate/lower-temperature comparator zone because Cairo has a lower mean annual temperature and lower typical summer maximum temperature range than Luxor/Aswan, with relatively higher humidity. For example, published climate datasets report mean annual temperatures of approximately 25.1 °C in Luxor and 26.6 °C in Aswan, compared with approximately 22.1 °C in Cairo [9,10,11]. This classification was intended to represent chronic regional climatic exposure rather than exact individual heat exposure on the day of surgery.

Comprehensive data were recorded for all enrolled patients where available. Demographic and baseline characteristics included age, sex, body mass index (BMI), relevant comorbidities, smoking status, and preoperative medication use.

Surgical and intraoperative records were reviewed for the type of cardiac procedure, cardiopulmonary bypass duration, aortic cross-clamp time, intraoperative lowest core temperature, rewarming temperature before completion of CPB, intraoperative antifibrinolytic use, heparin dose, peak activated clotting time (ACT), protamine dose, and use of additional hemostatic agents. These variables were extracted from the revised perioperative dataset and incorporated into the descriptive analysis and adjusted multivariable regression model.

Postoperative bleeding was assessed by cumulative chest tube drainage volume during the first 24 hours postoperatively. Coagulation and laboratory profiles included bleeding time (BT), platelet function (PF), prothrombin

Total patients screened for eligibility from operative and institutional records (n = 486)
Excluded before analysis (n = 86): incomplete records or missing 24-hour bleeding data (n = 31); emergency surgery (n = 18); re-do surgery (n = 12); pre-existing coagulopathy (n = 10); anticoagulants not discontinued before surgery (n = 15)
Final analyzed cohort (n = 400)
Hot-climate group/Upper Egypt (n = 200)
CABG n = 76; valve surgery n = 98; congenital/adult congenital heart disease n = 9; aortic surgery n = 17
Moderate/lower-temperature climate group/Lower Egypt (n = 200)
CABG n = 69; valve surgery n = 114; congenital/adult congenital heart disease n = 6; aortic surgery n = 11
Primary analysis: comparison of postoperative bleeding, transfusion requirement, re-exploration, and mortality between climate groups
Adjusted analysis: multivariable model including climate group, demographic variables, comorbidities, surgical subtype, CPB duration, cross-clamp time, temperature-management variables, and anticoagulation/hemostatic variables

Fig. 1. STROBE patient flow diagram. CABG, coronary artery bypass graft surgery; CPB, cardiopulmonary bypass.

time (PT), international normalized ratio (INR), activated partial thromboplastin time (aPTT), fibrinogen, platelet count, hemoglobin, and hematocrit measured preoperatively and at 24 hours postoperatively, according to available records.

Transfusion requirements were documented as a binary variable indicating whether blood product transfusion was required. Available perioperative records were also reviewed for packed red blood cell, platelet, fresh frozen plasma, cryoprecipitate, and other hemostatic blood product use when documented. Hemostatic management variables available for analysis included tranexamic acid use, tranexamic acid loading dose, and use of additional hemostatic agents.

All procedures were performed using comparable surgical techniques by experienced surgical teams in both centers. To minimize procedural heterogeneity, emergency surgery, re-do surgery, patients with pre-existing coagulopathy, patients with incomplete postoperative bleeding data, and patients receiving anticoagulants that were not discontinued before surgery were excluded.

There were no major differences in operative indications between the groups.

Perioperative anticoagulation was performed according to standard institutional CPB practice. Patients received an intraoperative bolus of unfractionated heparin according to body weight, targeting an ACT >480 seconds during CPB. Additional heparin boluses were administered when required to maintain ACT above this threshold. Patient-level heparin dose, peak ACT, and protamine dose were included in the perioperative dataset and analyzed as part of the operative/hemostatic profile.

Regarding antifibrinolytic therapy, most patients received tranexamic acid according to institutional protocols. Tranexamic acid use and loading dose were extracted from the perioperative dataset. Additional hemostatic-agent use, including additional protamine, fibrin sealant, or topical hemostatic agents, was also recorded and compared between groups.

The primary outcome was the incidence of mortality and morbidity. Secondary outcomes included total postoperative bleeding volume within the first 24 hours after surgery measured by cumulative chest tube drainage, bleeding at specific time intervals, blood product utilization, changes in coagulation parameters, and the incidence of re-exploration for bleeding.

A STROBE-compliant patient flow diagram was added to improve transparency of patient screening, exclusions, and final analytic enrollment by group and surgical subtype (Fig. 1).

Statistical Analysis

Data handling and analysis were conducted using SPSS software (v29; IBM Corp., Armonk, NY, USA). The pattern of data distribution was checked using the Shapiro-Wilk normality test and graphical review through histograms. Continuous variables with symmetric distribution were summarized as mean ± standard deviation (SD) and compared using the independent *t* test. Data showing skewed distribution were expressed as median with interquartile range (IQR) and assessed using the Mann-Whitney U test. Categorical variables were reported as counts and percentages and examined using the Chi-square test or Fisher's exact test, as appropriate. Linear regression was performed to assess factors associated with 24-hour postoperative bleeding amount. The adjusted model included climate group as the primary exposure together with age, sex, diabetes, hypertension, smoking, obesity, procedure type, CPB duration, aortic cross-clamp time, lowest intraoperative core temperature, rewarming temperature, heparin dose, peak ACT, protamine dose, tranexamic acid use, tranexamic acid loading dose, and use of additional hemostatic agents. Cold/moderate climate, female sex, absence of comorbidity, coronary artery bypass graft surgery (CABG) procedure type, no tranexamic acid use, and no additional hemostatic-agent use were used as reference categories where applicable. All analyses were performed using two-sided testing, and results were considered statistically significant when $p \leq 0.05$.

3. Results

Age, sex, and comorbidities (smoking, diabetes, hypertension, and obesity) were comparable between the investigated groups (Table 1).

Table 1. Demographic data and comorbidities of the studied groups.

Variable	Hot group (n = 200)	Cold group (n = 200)	*p*
Age (years)	50.08 ± 18.2	50.23 ± 17.04	0.930
Male sex	100 (50%)	94 (47%)	0.548
Female sex	100 (50%)	106 (53%)	-
Smoking	53 (26.5%)	45 (22.5%)	0.352
Diabetes	68 (34%)	69 (34.5%)	0.916
Hypertension	77 (38.5%)	84 (42%)	0.475
Obesity	39 (19.5%)	36 (18%)	0.701

Data are presented as mean ± SD or frequency (%).

Bleeding time and the change in bleeding time were significantly higher, both preoperatively and postoperatively, in the hot climate group compared with the cold climate group ($p < 0.001$). Platelet function and its change were significantly lower, both preoperatively and postoperatively, in the hot climate group compared with the cold climate group ($p < 0.001$). PT, aPTT, INR, and their changes showed no significant differences between the two groups, either preoperatively or postoperatively. Fibrinogen levels were comparable preoperatively between the groups but were significantly higher postoperatively in the hot climate group ($p = 0.05$). Within both groups, bleeding time, PT, aPTT, and INR were significantly higher postoperatively than preoperatively ($p < 0.001$), whereas platelet function and fibrinogen levels were significantly lower postoperatively ($p < 0.001$), indicating an association with residence in a hot climate (Table 2).

Bleeding amount, transfusion requirements, and reopening incidence were significantly higher in the hot climate group compared with the moderate/lower-temperature climate group ($p < 0.05$). Mortality rates were numerically higher in the hot climate group but were not statistically different between the two groups (Table 3).

Operative and perioperative variables are presented in Table 4. Procedure-type distribution did not differ significantly between groups ($p = 0.432$). CPB duration was significantly longer in the hot-climate group than in the moderate/lower-temperature climate group (107.17 ± 26.94 vs 99.16 ± 25.94 min, $p = 0.003$), and aortic cross-clamp time was also longer in the hot-climate group (72.67 ± 24.43 vs 67.23 ± 23.04 min, $p = 0.023$). Lowest core temperature, rewarming temperature, heparin dose, and peak ACT were comparable between groups. Protamine dose was slightly higher in the hot group (331.44 ± 56.94 vs 320.41 ± 54.94 mg, $p = 0.049$), while tranexamic acid loading dose was lower in the hot group (17.45 ± 8.68 vs 19.52 ± 8.18 mg/kg, $p = 0.014$). Tranexamic acid use was common in both groups but differed statistically (90.5% vs 96.0%, $p = 0.046$). Hemostatic-agent use did not differ significantly between groups ($p = 0.359$).

Multivariable linear regression analysis is presented in Table 5. After adjustment for demographic factors, comorbidities, procedure type, CPB duration, aortic cross-clamp time, intraoperative temperature variables, heparin dose, peak ACT, protamine dose, tranexamic acid variables, and hemostatic-agent use, hot-climate group remained independently associated with higher 24-hour postoperative bleeding amount (adjusted beta = 172.00 mL, 95% CI: 118.70 to 225.31, $p < 0.001$). The overall model explained 12.8% of the variance in bleeding amount (adjusted $R^2 = 0.079$).

4. Discussion

To the best of our knowledge, this is among the first studies to investigate the association between chronic regional climate differences and postoperative bleeding in Egyptian cardiac surgery patients.

In this retrospective cohort, BT and the change in BT were significantly higher both preoperatively and postoperatively in the hot-climate group than in the moderate/lower-temperature climate group. Platelet function and the change in platelet function were significantly diminished both preoperatively and postoperatively in the hot-climate group. PT, aPTT, INR, and their respective changes were not significantly different between groups, while postoperative fibrinogen was slightly but significantly higher in the hot-climate group. Bleeding amount, transfusion requirement, and reopening incidence were significantly higher in the hot-climate group, whereas mortality was not significantly different.

The higher postoperative fibrinogen concentration in the hot-climate group was unexpected because this group also had greater bleeding. This finding should not be interpreted as indicating superior clot quality. Fibrinogen behaves as both a coagulation factor and an acute-phase reactant. Cardiac surgery with CPB can trigger a systemic inflammatory response through blood contact with the extracorporeal circuit, ischemia-reperfusion, surgical trauma, and activation of coagulation and fibrinolysis. Previous cardiac-surgery studies have shown that fibrinogen may initially fall after CPB because of hemodilution and consumption, then recover during the early postoperative period; lower postoperative fibrinogen is associated with greater

Table 2. Coagulation profile of the studied groups.

Variable	Time point	Hot group (n = 200)	Cold group (n = 200)	*p*
	Preoperative	5.53 ± 1.48	4.72 ± 1.23	<0.001*
Bleeding time (min)	Postoperative	7.51 ± 1.66	6.01 ± 1.26	<0.001*
	Within-group *p*	<0.001*	<0.001*	
Change in bleeding time		1.99 ± 0.6	1.29 ± 0.46	<0.001*
	Preoperative	82.36 ± 6.88	87 ± 7.52	<0.001*
Platelet function (%)	Postoperative	76.16 ± 7.38	82.83 ± 8.18	<0.001*
	Within-group *p*	<0.001*	<0.001*	
Change in platelet function		–6.2 ± 2.26	–4.17 ± 2.54	<0.001*
	Preoperative	12.49 ± 0.57	12.58 ± 0.55	0.142
PT (sec)	Postoperative	17.02 ± 0.62	17.08 ± 0.61	0.270
	Within-group *p*	<0.001*	<0.001*	
Change in PT		4.52 ± 0.28	4.51 ± 0.3	0.615
	Preoperative	31.04 ± 1.13	31.12 ± 1.12	0.432
aPTT (sec)	Postoperative	57.62 ± 1.52	57.6 ± 1.42	0.884
	Within-group *p*	<0.001*	<0.001*	
Change in aPTT		26.58 ± 0.88	26.47 ± 0.9	0.218
	Preoperative	282.07 ± 16.79	279.23 ± 16.84	0.092
Fibrinogen (mg/dL)	Postoperative	259.92 ± 17.72	256.46 ± 17.46	0.050*
	Within-group *p*	<0.001*	<0.001*	
Change in fibrinogen		–22.15 ± 4.38	–22.77 ± 4.02	0.138
	Preoperative	1.05 ± 0.09	1.06 ± 0.09	0.642
INR	Postoperative	1.35 ± 0.09	1.36 ± 0.09	0.496
	Within-group *p*	<0.001*	<0.001*	
Change in INR		0.30 ± 0.03	0.30 ± 0.03	0.447

Data are presented as mean ± SD. *: Significant as $p \leq 0.05$. Change = postoperative – preoperative. PT, prothrombin time; aPTT, activated partial thromboplastin time; INR, international normalized ratio.

Table 3. Bleeding amount, transfusion need, reopening incidence, and mortality of the studied groups.

Outcome	Hot group (n = 200)	Cold group (n = 200)	*p*
Bleeding amount (mL)	762.68 ± 270.5	590.85 ± 242.82	<0.001*
Transfusion needed	142 (71%)	122 (61%)	0.035*
Reopening incidence	20 (10%)	9 (4.5%)	0.034*
Mortality	12 (6%)	7 (3.5%)	0.240

Data are presented as mean ± SD or frequency (%). *: Significant as $p \leq 0.05$.

bleeding risk, but higher fibrinogen may also reflect inflammatory activation or hemoconcentration rather than effective platelet-mediated hemostasis [12,13,14]. In the present cohort, the combination of higher fibrinogen with worse bleeding is therefore biologically plausible if the dominant abnormality in hot-climate patients is platelet dysfunction, altered platelet-endothelial interaction, or enhanced fibrinolysis rather than isolated fibrinogen deficiency. Clinically, this supports the use of platelet function assessment and global hemostatic evaluation rather than reliance on standard coagulation assays or fibrinogen concentration alone.

Hot climates impair hemostasis. One mechanistic link is temperature-induced platelet dysfunction. Exposure of platelets to temperatures exceeding physiological levels (38.5–42 °C) prior to activation markedly reduced thrombin-mediated haemostatic responses. These effects included suppression of platelet adhesion and aggregation, along with diminished ATP secretion and thromboxane A_2 synthesis. Heat stress completely prevented surface expression of activation markers P-selectin and CD63 and abolished the release of vascular endothelial growth factor. In contrast, concentrations of von Willebrand factor and endostatin remained notably elevated despite increased temperature. Thus, the release of platelet granule–derived proteins is influenced not only by conventional activating stimuli but also by local environmental conditions [15].

Similarly, Ke and colleagues [16] found that heat-exposed rats developed coagulopathy with marked platelet dysfunction and depletion of plasma fibrinogen. Heat-stressed rats had normal PLTs but severely reduced platelet aggregation and clot retraction, an effect partially reversed by fibrinogen supplementation. These results imply that heat can impair the quality of platelet plugs despite normal counts.

Table 4. Operative, temperature-management, anticoagulation, and hemostatic variables of the studied groups.

Variable	Hot group (n = 200)	Cold group (n = 200)	*p*
Procedure type			0.432
CABG	76 (38.0%)	69 (34.5%)	
Valve	64 (32.0%)	79 (39.5%)	
Combined CABG + Valve	34 (17.0%)	35 (17.5%)	
Aortic procedure	17 (8.5%)	11 (5.5%)	
Other CPB procedure	9 (4.5%)	6 (3.0%)	
CPB duration (min)	107.17 ± 26.94	99.16 ± 25.94	0.003*
Aortic cross-clamp time (min)	72.67 ± 24.43	67.23 ± 23.04	0.023*
Lowest core temperature (°C)	33.80 ± 0.63	33.78 ± 0.56	0.743
Rewarming temperature (°C)	36.39 ± 0.31	36.41 ± 0.31	0.509
Heparin dose (IU/kg)	353.00 ± 29.19	351.68 ± 29.36	0.654
Peak ACT (sec)	558.97 ± 39.38	557.21 ± 40.05	0.659
Protamine dose (mg)	331.44 ± 56.94	320.41 ± 54.94	0.049*
TXA loading dose (mg/kg)	17.45 ± 8.68	19.52 ± 8.18	0.014*
Tranexamic acid used	181 (90.5%)	192 (96.0%)	0.046*
Hemostatic agent used			0.359
None	167 (83.5%)	169 (84.5%)	
Additional protamine	17 (8.5%)	11 (5.5%)	
Fibrin sealant	8 (4.0%)	14 (7.0%)	
Topical hemostatic agent	8 (4.0%)	6 (3.0%)	

Data are presented as mean ± SD or frequency (%). *: Significant as $p \leq 0.05$. ACT, activated clotting time; TXA, tranexamic acid.

Table 5. Adjusted multivariable linear regression analysis for 24-hour postoperative bleeding amount.

Variable	Adjusted beta coefficient	95% CI	*p*
Hot climate group	172.00	118.70 to 225.31	<0.001*
Age (years)	0.21	–1.28 to 1.71	0.781
Male sex	21.04	–31.15 to 73.24	0.428
Diabetes	–12.60	–67.28 to 42.07	0.651
Hypertension	38.04	–14.55 to 90.63	0.156
Smoking	–8.84	–69.91 to 52.22	0.776
Obesity	–32.20	–98.39 to 33.99	0.339
CPB duration (min)	0.31	–2.12 to 2.75	0.800
Aortic cross-clamp time (min)	–0.36	–2.98 to 2.26	0.788
Lowest core temperature (°C)	11.40	–36.06 to 58.86	0.637
Rewarming temperature (°C)	16.43	–68.15 to 101.00	0.703
Heparin dose (IU/kg)	0.22	–0.90 to 1.33	0.704
Peak ACT (sec)	–0.16	–0.82 to 0.50	0.635
Protamine dose (mg)	0.24	–0.38 to 0.86	0.449
Tranexamic acid used	91.16	–38.82 to 221.14	0.169
TXA loading dose (mg/kg)	–1.60	–5.42 to 2.22	0.412
Any hemostatic agent used	–52.02	–122.66 to 18.61	0.148
Procedure: Aortic procedure	–2.30	–158.85 to 154.26	0.977
Procedure: Combined CABG + Valve	–42.84	–149.27 to 63.59	0.429
Procedure: Other CPB procedure	28.30	–115.62 to 172.21	0.699
Procedure: Valve	1.52	–67.32 to 70.36	0.965

Dependent variable: 24-hour postoperative bleeding amount. Reference categories: moderate/lower-temperature climate group, female sex, absence of comorbidity, CABG procedure type, no tranexamic acid use, and no additional hemostatic-agent use. Model $R^2 = 0.128$; adjusted $R^2 = 0.079$. *: Significant as $p \leq 0.05$.

Passive heat stress and exertion in the heat have been shown to increase fibrinolysis while inducing thrombocytosis [17]. Borgman and co-authors [18] stated that hyperthermia alone caused a surge in fibrinolytic activity and that dehydration in the heat further accelerated clot lysis.

Chronic heat exposure may leave individuals in a relatively hypocoagulable state (increased bleeding tendency), due both to dysfunctional platelets and enhanced fibrinolysis [19]. Conversely, classic surgical coagulopathies such as those from hypothermia usually also prolong bleeding. Shou and co-authors [20] compared platelet function across CPB strategies, maximum platelet aggregation and the gradient of aggregation were most markedly reduced in the hypothermic CPB group without aprotinin (ranging from −30% to −53% relative to baseline), and recovery was diminished in the post-bypass period compared with other groups. Hypothermic CPB with aprotinin caused less platelet dysfunction, and platelet aggregation in these patients was comparable to that observed with normothermic CPB, returning to or exceeding baseline values by the first postoperative day.

In contrast with our findings, Crawford and collaborators [21] assessed the seasonal variation in mean platelet volume and platelet total and found higher levels of fibrinogen and mean platelet volume in the spring and early summer correlating with increased thrombotic risk in cold months. This contrast may be attributed to the difference between short-term seasonal effects in temperate regions and chronic heat exposure in Upper Egypt.

In line with our results, Wu and co-authors [22] reported that winter and spring surgeries were associated with higher composite incidence of mortality and morbidities (26.8% and 18.0%) compared to summer (15.7%) and autumn (11.1%) surgeries ($p < 0.05$). However, they found peak drainage in spring and worse overall composite complications in winter. The difference may be attributed to the temperate climate in China and short-term seasonal effects, whereas our patients in Upper Egypt experience chronic heat exposure, leading to platelet dysfunction and higher postoperative bleeding.

Also, Shuhaiber and colleagues [23] analyzed 12,221 cardiac surgery patients in the United Kingdom and reported higher risk-adjusted hospital mortality and longer length of stay (LOS) during winter. Similarly, a study by Torabipour and co-authors [24] found that season significantly influenced LOS after CABG in Iran, with the longest stays in winter and the shortest in summer. In contrast, Nemati [25] found no significant differences in postoperative mortality, morbidity, or LOS among the four seasons in Iran.

Comparison with studies from tropical and subtropical regions further supports the clinical relevance of our findings. In Ghana, Tettey and colleagues [26] identified postoperative platelet count and reduction in platelet count as important predictors of postoperative bleeding and transfusion after cardiac surgery, emphasizing the importance of platelet-related mechanisms in a West African cardiac surgical setting. In Nigeria, Falase and colleagues [27] reported open-heart surgical outcomes using CPB and included CPB duration and aortic cross-clamp time as key operative variables, supporting the reviewer-driven addition of these covariates to the present adjusted model. In India, Varghese and colleagues [28] described platelet-function abnormalities during CPB, consistent with the concept that platelet dysfunction may be a major driver of post-bypass bleeding in warm-climate practice environments. These studies differ from the present work because most evaluated perioperative CPB physiology, institutional outcomes, or seasonal/perioperative risk rather than chronic residence in an arid hot climate. Nevertheless, the direction of evidence is consistent: in hot, tropical, or subtropical settings, bleeding after CPB is strongly influenced by platelet function, transfusion practice, antifibrinolytic use, and operative complexity. Our findings may therefore be generalizable to other arid hot regions of the Middle East and North Africa, while prospective validation is still needed in Southeast Asian and sub-Saharan African centers with standardized blood-management protocols.

Also, Sayed and collaborators [29] evaluated the effect of core temperature on postoperative outcomes in elective on-pump CABG. Hypothermia was associated with prolonged PT and PTT, increased blood loss, and higher transfusion requirements compared with normothermia.

In line with our results, Abdelhameed and co-authors [1] reported that patients exposed to hyperthermia (HT) during cardiac surgery had significantly longer activated clotting times, diminished postoperative hemoglobin (Hb) and platelets (PLTs), and reduced ADP-induced platelet aggregation, which correlated with higher postoperative bleeding and increased transfusion requirements. However, they observed significantly prolonged aPTT and INR in HT patients. The cause of this disagreement is likely due to the type and duration of heat exposure.

The present findings should be interpreted within the context of perioperative confounding. Intraoperative temperature management, CPB duration, aortic cross-clamp time, heparin responsiveness, ACT trends, protamine reversal, antifibrinolytic dosing, and transfusion thresholds may all influence postoperative bleeding. In the revised analysis, patient-level perioperative variables were incorporated into a multivariable regression model. Hot-climate group remained independently associated with higher 24-hour bleeding amount after adjustment for demographic, clinical, procedural, CPB-related, temperature-related, and anticoagulation/hemostatic covariates. Nevertheless, given the retrospective observational design, this association should not be interpreted as definitive causal evidence.

Limitation

Limitations of this study include its retrospective observational design, which may introduce selection bias, information bias, and residual confounding despite adjustment. Climatic exposure was classified using regional averages based on residence and surgical center rather than individual-level exposure measurements, occupational heat exposure, hydration status, or exact ambient conditions on the day of surgery. Although the adjusted model incorporated procedure type, CPB duration, cross-clamp time, core temperature, rewarming temperature, heparin dose, peak ACT, protamine dose, tranexamic acid variables, and hemostatic-agent use, other unmeasured factors may have influenced bleeding, including surgeon-specific decisions, transfusion thresholds, perioperative fluid balance, platelet function assay variability, and center-level practice differences. In addition, transfusion was analyzed mainly as requirement status rather than complete product-specific dose exposure, and follow-up was limited to early postoperative outcomes without long-term assessment of hemostatic complications. Therefore, the findings should be interpreted as adjusted associations that require confirmation in prospective multicenter studies.

Prospective, multicenter studies with standardized perioperative protocols are warranted to validate these findings. Future studies should prospectively collect patient-level climatic exposure, operative-day ambient temperature and humidity, hydration indices, CPB duration, aortic cross-clamp time, full intraoperative core temperature curves, ACT trends, heparin and protamine doses, antifibrinolytic dosing, and detailed transfusion/hemostatic-agent exposure. Mechanistic studies should also explore links between environmental heat exposure, platelet function, fibrinolysis, endothelial activation, and vascular responses in cardiac surgery patients living in hot climates [30].

5. Conclusions

Regional environmental factors were associated with perioperative hemostasis and bleeding outcomes in cardiac surgery with cardiopulmonary bypass. Patients from hot-climate regions showed higher postoperative bleeding, greater transfusion requirements, and increased re-exploration rates, and the association remained clinically relevant after adjustment for operative and perioperative confounders. These findings suggest two practical measures: first, patients from hot-climate regions should undergo preoperative platelet function testing where available, in addition to standard PT, aPTT, INR, platelet count, and fibrinogen assessment; second, these patients may benefit from standardized and adequately dosed antifibrinolytic therapy, careful ACT/heparin-protamine monitoring, and intensified postoperative chest-drainage surveillance during the first 24 hours. These recommendations should be implemented within institutional blood-management protocols and validated prospectively before adoption as universal guidelines [31].

Availability of Data and Materials

The data involved in this study are available from the corresponding author upon reasonable request.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by AMah, AMGT, AME, BAE, HMAbd, INE and HMAbo. The first draft of the manuscript was written by MAZE, KE, ME and AMoh and all authors commented on previous versions of the manuscript. All authors participated in writing the article. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study follows the Declaration of Helsinki and took place over a two-year period between June 2023 and June 2025, following approval from the ethical committee of Al-Azhar University Hospitals, Cairo, Egypt (Approval No: 12/2025), with all patients providing informed written consent.

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Conflicts of Interest

The authors declare no conflicts of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.31083/50664.

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