

ROLE OF TWO DIFFERENT BIOCOMPATIBLE COATED CPB CIRCUITS AND ITS IMPACT ON POSTOPERATIVE LEUKOCYTIC COUNT IN PATIENTS WITH CABG

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Abstract

Background: Cardiopulmonary bypass (CPB) triggers a profound inflammatory reaction from contact of blood with artificial surfaces, the activation of leukocytes and other inflammatory processes. Biocompatible coatings such as phosphorylcholine and balanced polymer have been used to minimise this.

Objective(s): To compare the impact of two types of biocompatible coated CPB circuits on postoperative levels of leukocytes in patients undergoing coronary artery bypass grafting.

Methodology: In this study, one hundred patients were scheduled for elective coronary artery bypass graft surgery. The study participants were split into two groups according to the type of coating applied to the CPB circuit: balanced coated circuits and

phosphorylcholine coated circuits. Demographic and operative details and leukocyte count were measured before surgery, immediately after surgery and at seventy-two hours after surgery. Data was analyzed to compare the results of the two groups.

Results: There was an elevation in the leukocyte count in both groups after surgery, reflecting the inflammatory response due to CPB. But the 72 hours postoperative leukocyte count was significantly greater in the phosphorylcholine group than in the balanced coating group. There was no significant difference in the immediate postoperative leukocyte count. Demographic and operative data were similar between both groups, suggesting similar patient populations.

Conclusion(s): Postoperative leukocytic response is lower in balanced coated CPB circuits than phosphorylcholine coated circuits, especially in the late postoperative period. This study highlights the increased biocompatibility of the balanced coating and its impact on the clinical outcomes for CABG surgery.

INTRODUCTION

Cardiopulmonary bypass (CPB) is an essential component of modern cardiac surgery and is widely used during coronary artery bypass grafting (CABG) to maintain systemic circulation and oxygenation while allowing the heart to remain motionless during surgical intervention. Despite its life-saving role, CPB is associated with significant physiological disturbances because circulating blood comes into direct contact with the artificial non-endothelial surfaces of the extracorporeal circuit. This exposure initiates a complex systemic inflammatory response characterized by activation of the complement system, stimulation of leukocytes, platelet aggregation, cytokine release, and endothelial dysfunction. The inflammatory cascade contributes to postoperative complications including pulmonary dysfunction, renal impairment, coagulopathy, tissue edema, prolonged ventilation, and delayed recovery. As a result, improving the biocompatibility of CPB circuits has become an important objective in cardiac surgery research and clinical practice. Various coating

technologies have therefore been developed to minimize blood-surface interaction and attenuate inflammatory activation during extracorporeal circulation. Among these technologies, phosphorylcholine (PC) coating and balanced polymer coating have emerged as important biocompatible surface modifications designed to reduce postoperative inflammatory complications and improve patient outcomes after CABG procedures (1).

Phosphorylcholine coating was developed to mimic the phospholipid structure of natural cell membranes and create a biologically inert interface between blood and the artificial surfaces of CPB circuits. The phospholipid head group of phosphorylcholine closely resembles the outer surface of erythrocytes and endothelial cells, thereby reducing protein adsorption, platelet adhesion, complement activation, and leukocyte stimulation during bypass. Previous clinical and experimental investigations have demonstrated that PC-coated circuits are associated with lower inflammatory marker release, improved preservation of platelet counts, and reduced activation of circulating immune cells when compared with uncoated systems. Studies have also shown better maintenance of antithrombin III activity and serum albumin levels in patients exposed to PC-coated circuits, suggesting a reduction in both coagulation and inflammatory disturbances during extracorporeal circulation (2). In addition, several reports indicate that PC-coated circuits may contribute to shorter ventilation times, improved renal function parameters, and reduced postoperative inflammatory burden in CABG patients (3). Although these findings support the biocompatibility of PC-coated systems, the precise effect of phosphorylcholine coating on postoperative leukocyte dynamics remains insufficiently explored, leaving an important gap in understanding the immunologic impact of this technology (4).

The persistent inflammatory response associated with CPB has encouraged the development of newer and more advanced coating technologies aimed at improving hemocompatibility and reducing postoperative morbidity. Balanced coating represents one such innovation and combines multiple biocompatibility strategies through hydrophilic polymer layers and negatively charged surface elements to minimize activation of blood components. This technology is intended to reduce

complement activation, leukocyte adhesion, thrombin generation, oxidative stress, and endothelial injury during extracorporeal circulation (5). Comparative studies evaluating balanced-coated circuits and phosphorylcholine-coated circuits have suggested differences in platelet preservation and inflammatory modulation, indicating that surface chemistry plays a critical role in determining blood-material interactions during CPB (6). However, despite growing evidence regarding biochemical markers of inflammation and platelet behavior, leukocyte response patterns have not been consistently investigated as primary outcome measures. Leukocyte count remains one of the most accessible and clinically significant indicators of postoperative inflammatory response, and abnormal postoperative leukocytosis has been linked to complications such as infection, organ dysfunction, prolonged intensive care stay, and delayed healing after cardiac surgery (7). Therefore, evaluating leukocyte trends following CABG may provide valuable insight into the true immunomodulatory effects of different CPB surface coatings.

Several investigators have emphasized that CPB-induced inflammatory activation is multifactorial and involves both mechanical and biochemical pathways. Exposure of blood to artificial surfaces causes complement activation, neutrophil degranulation, platelet-leukocyte interaction, and release of pro-inflammatory cytokines such as interleukin-6 and tumor necrosis factor-alpha. These events contribute to endothelial injury and microvascular dysfunction, which can impair postoperative organ perfusion and oxygen delivery (8). Experimental studies have shown that biomimetic coatings such as phosphorylcholine reduce cellular adhesion and inflammatory signaling by creating a more physiologic blood-contacting surface (9). Similarly, balanced polymer coatings attempt to provide broader protection against inflammatory activation by integrating hydrophilic and charge-based modifications that stabilize blood-material interaction throughout bypass (10). Although both technologies appear promising, the literature remains inconsistent regarding their comparative effectiveness in reducing postoperative inflammatory consequences. Some studies report significant reductions in inflammatory markers and blood cell activation with coated circuits, whereas others demonstrate only modest or clinically insignificant improvements in patient outcomes. These

discrepancies may result from differences in study design, patient characteristics, operative variables, and outcome measures used across investigations. Consequently, additional focused research comparing these coating systems under similar clinical conditions is necessary to clarify their true clinical benefit.

The inflammatory response generated during cardiopulmonary bypass has important implications for postoperative recovery and overall surgical outcomes in CABG patients. Leukocyte activation plays a central role in this process because activated leukocytes contribute to endothelial damage, capillary leakage, oxidative stress, and organ dysfunction following surgery. Postoperative leukocytosis is therefore frequently observed after CPB and is often considered an indicator of systemic inflammatory stress. Persistent or excessive leukocyte elevation may correlate with adverse postoperative events including pulmonary complications, renal dysfunction, prolonged hospitalization, and increased morbidity (11). Despite its clinical relevance, leukocyte count has received comparatively limited attention in studies evaluating CPB coating technologies, with greater emphasis traditionally placed on platelet preservation or cytokine analysis. Since leukocyte count is routinely available, inexpensive, and clinically meaningful, understanding its postoperative behavior in response to different coating technologies may offer practical guidance for optimizing CPB biocompatibility in routine cardiac surgery practice.

In addition to inflammatory activation, CPB is associated with significant hematologic disturbances including platelet consumption, coagulation abnormalities, and complement-mediated cellular injury. Platelet activation during bypass contributes to bleeding tendencies, increased transfusion requirements, and postoperative complications. Biocompatible coatings were initially introduced largely to reduce platelet activation and preserve coagulation homeostasis during extracorporeal circulation. Early investigations into phosphorylcholine-coated circuits demonstrated reduced platelet consumption and lower protein adsorption compared with conventional uncoated systems (6). These findings provided indirect evidence that leukocyte activation might also be attenuated due to decreased inflammatory stimulation at the blood-surface interface. Later studies using

experimental models further supported this hypothesis by demonstrating reduced leukocyte-endothelial interactions on biomimetic polymer-coated surfaces (9). However, although platelet preservation has been repeatedly documented, fewer studies have directly evaluated postoperative leukocyte patterns, and the available findings remain inconsistent. Some reports suggest modest reductions in leukocyte activation with coated systems, whereas others fail to demonstrate substantial differences between coating technologies. Such inconsistencies highlight the need for more targeted investigations focusing specifically on leukocyte dynamics after CABG procedures.

The introduction of balanced polymer coating has further expanded the field of CPB biocompatibility research. Unlike single-mechanism coating systems, balanced coating integrates multiple surface modifications intended to provide comprehensive protection against blood activation pathways during bypass. By reducing complement activation, leukocyte adhesion, thrombin generation, and oxidative injury simultaneously, balanced coating aims to produce greater hemodynamic stability and inflammatory control than earlier coating technologies (10). Preliminary studies suggest potential advantages in reducing inflammatory complications and improving postoperative recovery, but comparative evidence between balanced-coated circuits and phosphorylcholine-coated circuits remains limited. Most available studies focus on biochemical inflammatory markers rather than clinically observable hematologic responses such as leukocyte count changes. Consequently, uncertainty persists regarding which coating technology more effectively attenuates postoperative inflammatory response following CABG surgery.

Given the continuing burden of postoperative inflammatory complications associated with cardiopulmonary bypass, identifying the most effective biocompatible coating technology remains clinically important. While phosphorylcholine coating and balanced coating both aim to minimize blood-surface interaction and inflammatory activation, direct comparisons of their effects on postoperative leukocyte trends are scarce in the current literature. Leukocyte count represents a clinically relevant marker of immune activation and inflammatory stress, and its evaluation may help determine the comparative immunomodulatory effectiveness of different CPB coating systems.

Therefore, this study aims to compare the postoperative leukocyte count in patients undergoing coronary artery bypass grafting using phosphorylcholine-coated and balanced-coated cardiopulmonary bypass circuits. By examining leukocyte dynamics following surgery, the study seeks to contribute evidence regarding the relative ability of these coating technologies to reduce inflammatory response and improve postoperative outcomes in CABG patients (12).

Literature Review

Gorter et al. (2025) compared activated clotting time targets of 400 and 480 seconds in adult cardiac surgery patients undergoing cardiopulmonary bypass. Their findings showed no significant differences in blood transfusion requirements, bleeding complications, thrombotic events, or postoperative outcomes between the two groups. Leukocyte counts increased after surgery in both groups, indicating that altering anticoagulation intensity alone did not significantly influence inflammatory activation during bypass procedures. The researchers suggested that lower anticoagulation exposure may be clinically safe but insufficient to suppress postoperative leukocytosis. Huang et al. (2025) reviewed inflammatory regulation strategies during cardiopulmonary bypass and highlighted that complement activation, cytokine release, endothelial injury, and leukocyte activation contribute to postoperative systemic inflammatory response syndrome and leukocytosis following cardiac surgery procedures [13, 14].

Margetson et al. (2022) reported that Balance-coated cardiopulmonary bypass circuits are increasingly used in modern cardiac surgery because hydrophilic polymeric surfaces improve hemocompatibility and reduce blood trauma during extracorporeal circulation. Their institutional findings demonstrated stable perfusion outcomes and satisfactory clinical performance with coated systems. However, postoperative leukocyte counts and inflammatory markers were not directly measured, leaving uncertainty regarding the coating's immunologic effects. Saleem et al. (2023) compared phosphorylcholine-coated and Balance-coated circuits and found postoperative platelet reduction in both groups, although phosphorylcholine-coated systems demonstrated relatively

improved platelet preservation. The authors suggested that preservation of platelets may indirectly reduce inflammatory amplification and improve postoperative hemostasis. Nonetheless, leukocyte-specific inflammatory responses remained insufficiently investigated in both coating technologies [15, 16].

Zangrillo et al. (2024) reviewed inflammatory complications associated with cardiopulmonary bypass and emphasized that exposure of blood to artificial circuit surfaces activates complement pathways, leukocyte priming, cytokine release, and endothelial dysfunction. The authors highlighted the importance of biocompatible coatings in reducing inflammatory stress during cardiac surgery. Ali et al. (2023) similarly examined extracorporeal circuit surface modifications and reported that phospholipid-mimetic and polymer-based coatings decrease protein adsorption, neutrophil adhesion, and complement activation. Their findings suggested that coating selection significantly influences postoperative inflammatory responses and blood preservation during bypass procedures. Lorusso et al. (2022) further explained that phosphorylcholine and polymer coatings improve blood-biomaterial compatibility by reducing leukocyte adhesion and activation during extracorporeal circulation [18–20].

Warren et al. (2020) investigated mechanisms of leukocyte activation during cardiopulmonary bypass and identified leukocyte-platelet aggregation, endothelial injury, and systemic inflammatory signaling as major contributors to postoperative inflammatory response syndrome. Their review emphasized that improved biocompatible coatings may reduce leukocytosis by minimizing cellular adhesion and protein deposition on artificial circuit surfaces. Ferreira et al. (2023) observed that phosphorylcholine-coated and polymer-coated circuits were associated with reduced cytokine release and complement activation compared with conventional systems, indicating decreased inflammatory burden after surgery. Banerjee et al. (2024) concluded that phosphorylcholine and Balance coatings effectively reduce complement activation and leukocyte adhesion, although postoperative inflammatory activation may still persist despite modern coating technologies during cardiopulmonary bypass procedures [22–24].

Materials and Methods

A cross-sectional study design was used to evaluate postoperative leukocytic response among patients undergoing coronary artery bypass grafting (CABG) with cardiopulmonary bypass (CPB). The research was conducted at the Punjab Institute of Cardiology over a duration of four months following approval of the synopsis. A total of 100 patients were included in the study. Sample size was calculated using the standard prevalence formula with a 95% confidence level, expected prevalence of 50%, and allowable margin of error of 0.098. Non-probability convenient sampling technique was employed to recruit participants. Adult patients aged 18 to 70 years undergoing elective CABG procedures with the use of biocompatible coated CPB circuits were enrolled after obtaining informed written consent from all participants.

The inclusion criteria consisted of patients undergoing elective CABG surgery with cardiopulmonary bypass using phosphorylcholine-coated or balanced-coated circuits. Both male and female patients between 18 and 70 years of age were included in the study. Patients were required to provide written informed consent prior to participation. Patients undergoing emergency cardiac surgeries were excluded from the study. Individuals with pre-existing infection, autoimmune disorders, leukopenia, leukocytosis, or those refusing consent were also excluded. Biocompatible coated cardiopulmonary bypass circuits including phosphorylcholine-coated systems and balanced-coated systems were used during surgical procedures. Automated hematology analyzers were utilized for measuring postoperative leukocyte counts and inflammatory markers in all enrolled patients during the postoperative monitoring period.

Leukocytic response following cardiopulmonary bypass was assessed using automated hematology analyzers during the immediate postoperative period. Baseline laboratory parameters included total leukocyte count, white blood cell count, and C-reactive protein levels. Normal baseline total leukocyte count and white blood cell count ranged between 4000 and 11000 cells/ μ L, while normal C-reactive protein level was below 10 mg/L. Ethical approval for the study was obtained prior to data collection, and all participants were informed regarding the objectives and procedures of the

research through written informed consent. Confidentiality of patient information was strictly maintained throughout the study. Participants were informed that they could withdraw from the research at any stage without any consequences to their treatment or medical care.

Prospective data were collected from patients undergoing CABG surgery using different types of biocompatible coated CPB circuits. Preoperative leukocyte levels were recorded before surgery, while postoperative measurements were obtained immediately after the operation. Clinical and intraoperative variables including CPB duration, coating material, aortic clamp time, and activated clotting time were documented systematically. Independent variables included the type of CPB coating used, while dependent variables consisted of postoperative leukocytic count changes, total leukocyte count, neutrophil percentage, white blood cell count, and C-reactive protein levels. Statistical analysis was performed using IBM SPSS Statistics. Descriptive statistics were used to summarize demographic and clinical data, while independent t-tests and correlation analyses were applied to evaluate associations between leukocytic response, CPB duration, and coating type.

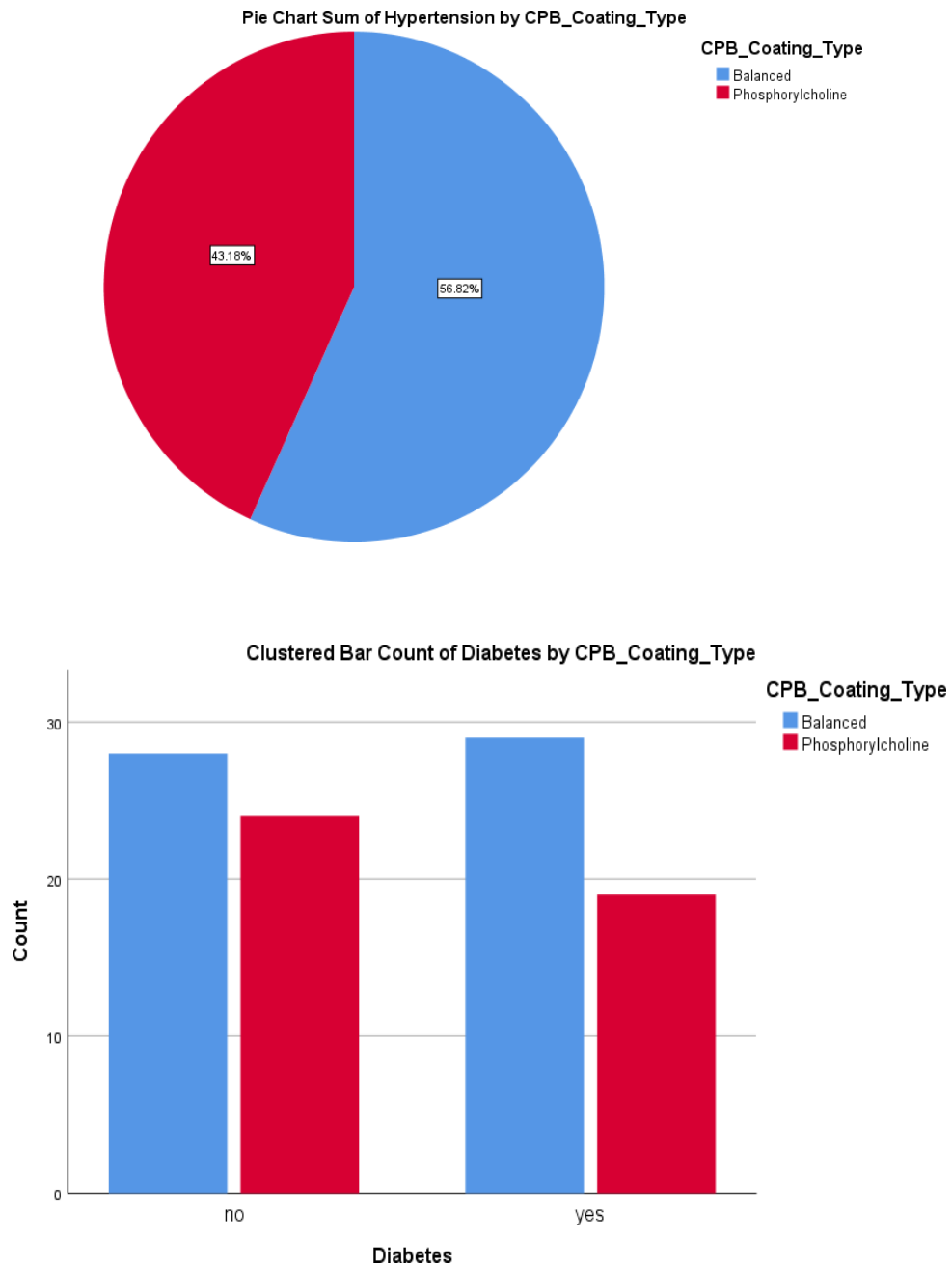
Results

The study included 100 patients with a mean age of 56.96 ± 10.14 years, mean height of 166.84 ± 10.37 cm, and mean weight of 75.73 ± 11.78 kg. Cardiopulmonary bypass (CPB) and aortic cross-clamp times averaged 107.69 ± 20.52 minutes and 64.78 ± 15.61 minutes, respectively. Overall, the cohort demonstrated a progressive postoperative increase in total leukocyte count (TLC), rising from preoperative levels to immediate and 72-hour postoperative measurements, suggesting an ongoing systemic inflammatory response following CPB.

Distribution of Hypertension and Diabetes mellitus by CPB Coating Type

The sample showed nearly equal gender distribution (51% male, 49% female). Comorbid conditions were also relatively balanced with 58.82% and phosphorycholine had the 43.18% and both groups have total 48% diabetes mellitus. CPB coating allocation was 57% balanced coating and 43%

phosphorylcholine coating, indicating adequate representation of both study groups for comparative analysis. Overall, baseline characteristics and comorbidity profiles were comparable between groups without major imbalances.



CPB Time, Aortic Clamp and ACT (Activated Clotting Time) comparison by the CPB Coating Type

Intraoperative parameters, including CPB time, aortic cross-clamp time, and activated clotting time (ACT), showed no statistically significant differences between the balanced and phosphorylcholine coating groups. Although the balanced group had a slightly longer mean CPB time (109.44 vs 105.37 minutes) and the phosphorylcholine group had a slightly longer aortic clamp time (67.74 vs 62.54 minutes), these differences were not statistically significant ($p > 0.05$). ACT values were also comparable between both groups, indicating similar intraoperative anticoagulation and procedural profiles.

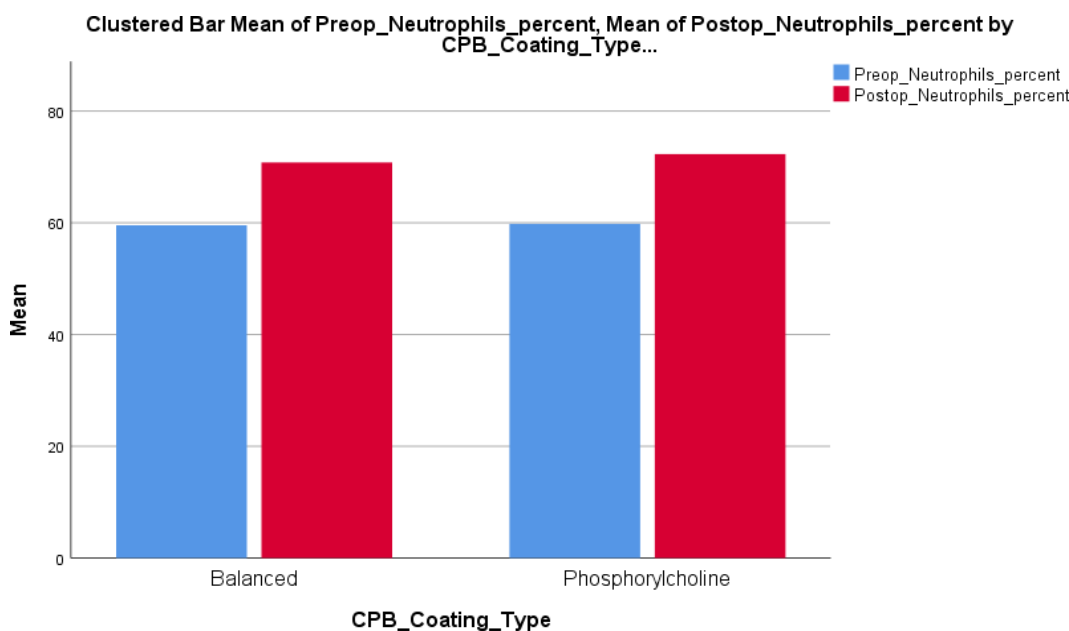
Group Statistics					
	CPB_Coating_Type	N	Mean	Std. Deviation	Std. Error Mean
CPB_Time_min	Balanced	57	109.44	19.457	2.577
	Phosphorylcholine	43	105.37	21.856	3.333
Aortic_Clamp_Time_min	Balanced	57	62.54	16.329	2.163
	Phosphorylcholine	43	67.74	14.258	2.174
ACT_seconds	Balanced	57	500.28	58.967	7.810
	Phosphorylcholine	43	504.53	55.559	8.473

Inflammatory and hematological markers demonstrated more notable postoperative trends. Neutrophil percentages increased in both groups postoperatively, with no significant intergroup differences. IL-6 levels were elevated postoperatively in both groups without statistically significant differences, although slight variations were observed. However, TLC at 72 hours postoperatively was

significantly higher in the phosphorylcholine group compared to the balanced group ($p = 0.037$), indicating a potentially greater delayed inflammatory response in this group.

Preoperative and Postoperative Neutrophil Percentage Comparison

Overall, most perioperative and inflammatory variables did not show statistically significant differences between the two CPB coating strategies. The only notable exception was the significantly higher 72-hour postoperative TLC in the phosphorylcholine group, suggesting a differential late inflammatory response. Other inflammatory markers, including neutrophils and IL-6, as well as intraoperative parameters, remained comparable between groups. These findings suggest broadly similar clinical and biochemical profiles between the two coatings, with limited but measurable variation in late leukocyte response.



Discussion

The current study demonstrated that cardiopulmonary bypass (CPB) in both balanced and phosphorylcholine-coated circuits is associated with a marked postoperative inflammatory response,

evidenced by increased leukocyte counts after surgery. However, the magnitude of this response differed between the two coatings, with the balanced-coated group showing a significantly lower total leukocyte count at 72 hours postoperatively. This finding suggests that while both coatings reduce blood-surface interaction to some extent, balanced coating provides superior modulation of the delayed inflammatory response, indicating improved biocompatibility in the later postoperative phase.

Baseline demographic, clinical, and intraoperative variables were comparable between the two groups, including CPB time, aortic cross-clamp time, and activated clotting time (ACT). This strengthens the validity of attributing observed differences in inflammatory markers to coating type rather than procedural or patient-related confounders. Although phosphorylcholine coating is widely recognized for improving hemocompatibility and reducing early complement activation, the present findings indicate that this effect may not be sufficient to fully suppress leukocyte-mediated inflammation over time. Thus, the inflammatory cascade appears to persist despite surface modification, particularly in the phosphorylcholine group.

The pattern of inflammatory biomarkers further supports these observations. Both groups showed postoperative increases in neutrophil percentage and interleukin-6 (IL-6), reflecting the expected systemic inflammatory response to CPB. However, differences between groups were not statistically significant for these early markers, suggesting similar initial inflammatory activation. In contrast, the significant divergence in total leukocyte count at 72 hours indicates that the key distinction between coatings lies in their ability to modulate sustained or late-phase inflammation rather than immediate postoperative responses.

Overall, the findings suggest that while both CPB coatings are effective in maintaining procedural equivalence and reducing early inflammatory insult, balanced coating demonstrates a comparatively stronger effect in attenuating prolonged leukocytic activation. This indicates that coating composition plays a critical role in long-term inflammatory control following CPB. Although phosphorylcholine coating improves biocompatibility, it does not completely eliminate

postoperative inflammatory activity. Therefore, advancements in coating technology, particularly those enhancing sustained anti-inflammatory performance, may contribute to improved postoperative outcomes in cardiac surgery.

CONCLUSION

This study concludes that both balanced and phosphorylcholine coated CPB circuits are linked with an increase in the number of leukocytes in the body after the surgery because of the inflammatory response caused by cardiopulmonary bypass, but balanced coated circuits are found to be less leukocytic at 72 hours postsurgery. Although the immediate postoperative inflammatory reaction is not any different in the two groups, the considerable difference that is witnessed at the latter stages shows that coating type can have a major role in regulation of postoperative inflammation. Since baseline characteristics as well as operative variables were similar, the difference observed could be attributed to the effect of coating. Thus, balanced coated CPB circuits can have better biocompatibility and lead to better postoperative outcomes of CABG surgery patients due to a decrease in inflammatory response.

Based on the findings of this study, it is recommended that CPB circuits with balanced coating be preferentially used in coronary artery bypass grafting (CABG) procedures, as they demonstrated a comparatively reduced postoperative inflammatory response, particularly at 72 hours. Future research should focus on strengthening the evidence base through larger sample sizes and multicenter designs to improve generalizability. In addition, expanding the panel of inflammatory biomarkers—such as interleukin-6 (IL-6), C-reactive protein (CRP), and other cytokines—would provide a more comprehensive understanding of the inflammatory cascade associated with different CPB coatings. Longitudinal follow-up studies are also essential to assess long-term clinical outcomes, complications, and potential differences in recovery trajectories between coating types.

The limitations of this study include its relatively small sample size and single-center design, which may restrict the external validity of the findings. Furthermore, the assessment of inflammatory

response was limited primarily to leukocyte counts, without incorporating a broader range of inflammatory mediators. The absence of long-term follow-up data also limits conclusions regarding sustained clinical outcomes and postoperative complications. Additionally, potential variations in surgical technique and perioperative management were not fully controlled, which may have introduced unmeasured confounding factors into the analysis.

REFERENCES

- Al-Fares A, et al. Surface-modified extracorporeal circuits and their impact on inflammatory activation. *Crit Care*. 2021.
- Ali JM, et al. Advances in biocompatible strategies for extracorporeal circulation. *Perfusion*. 2023.
- Al-Sofi A, et al. Effect of phosphorylcholine-coated cardiopulmonary bypass circuits on postoperative inflammatory response and early clinical outcomes. *Heart Surg Forum*. 2019.
- Amoako K, et al. Antifouling zwitterionic polymer coatings for blood-bearing medical devices. *Langmuir*. 2025.
- Banerjee D, et al. Strategies to attenuate inflammatory response associated with cardiopulmonary bypass. *Front Surg*. 2024.
- Banerjee D, et al. Strategies to attenuate maladaptive inflammatory response associated with cardiopulmonary bypass. *Frontiers in Surgery*. 2024.
- Barbu M, et al. Cardiopulmonary bypass: Clinical studies in cardiac surgery patients. 2022.
- Bierer JD, et al. Complement activation by the artificial surface of cardiopulmonary bypass is a persistent clinical problem. *Sci Rep*. 2025.
- Bolat A, et al. The effect of phosphorylcholine-coated cardiopulmonary bypass circuits on morbidity and mortality in patients with congenital open cardiac surgery. *Journal of Health Sciences and Medicine*. 2021.

- Casselmann F, et al. 2024 EACTS/EACTAIC guidelines on patient blood management in adult cardiac surgery. *Eur J Cardiothorac Surg*. 2024.
- Chacon Arenas DF, et al. Comparison of the frequency and intensity of systemic inflammatory response in patients undergoing cardiac revascularization surgery with and without extracorporeal blood flow. 2023.
- Condello I, et al. Health technology assessment of cardiopulmonary bypass circuit with and without phosphorylcholine coating. *Life (Basel)*. 2024.
- De Somer F, et al. Phosphorylcholine coating of extracorporeal circuits reduces platelet consumption and complement activation. *J Thorac Cardiovasc Surg*. 2000.
- Elgariah M, et al. Correlation between duration of cardiopulmonary bypass and morbidity and mortality in adult cardiac surgery. *International Journal of Medical Arts*. 2024.
- Ferreira LO, et al. Biochemical changes in cardiopulmonary bypass and inflammation. *J Clin Med*. 2023.
- Foroughi M, et al. Postoperative considerations of cardiopulmonary bypass. *Postoperative Critical Care for Adult Cardiac Surgical Patients*. 2026.
- Fujii Y, et al. Reduction of oxidative stress and leukocyte activation using PMEAC-coated CPB circuits. *Artif Organs*. 2022.
- Gorter KAM, et al. Comparison of two activated clotting time targets during cardiac surgery with cardiopulmonary bypass. *J Extra Corpor Technol*. 2025.
- Hanedan MO, et al. Non-coated cardiopulmonary bypass circuits compared using different activated clotting times. *Braz J Cardiovasc Surg*. 2020.
- Hessel EA, et al. Guidelines for conduct of cardiopulmonary bypass. *Journal of Cardiothoracic and Vascular Anesthesia*. 2021.
- Hosoyama K, et al. Poly-2-methoxyethylacrylate-coated cardiopulmonary bypass circuit can reduce transfusion of platelet products compared to heparin-coated circuit during aortic arch surgery. *J Artif Organs*. 2016.

- Huang R, et al. Expert consensus on perioperative inflammation management in cardiac surgery involving CPB. *J Emerg Crit Care Med*. 2025.
- Kahraman E, et al. Impact of phosphorylcholine-coated cardiopulmonary bypass circuits on postoperative inflammatory response and clinical outcomes in coronary artery bypass grafting. *J Cardiothorac Surg*. 2024.
- Korhan GÇ, et al. Inflammatory response in cardiopulmonary bypass process. *MEHES Journal*. 2024.
- Laffey JG, et al. The systemic inflammatory response to cardiac surgery: implications for postoperative leukocytosis and organ dysfunction. *Anesthesiology*. 2017.
- Lorusso R, et al. Blood-biomaterial interactions during extracorporeal circulation. *Ann Thorac Surg*. 2022.
- Margetson T, et al. Overview of cardiopulmonary bypass techniques and outcomes. *J Thorac Dis*. 2022.
- Motoyama H, et al. Clinical evaluation of PMEA-coated cardiopulmonary bypass circuits on inflammatory response and hemostasis. *Interact Cardiovasc Thorac Surg*. 2016.
- Nishiyama T, et al. Influence of phosphorylcholine-coated circuits on postoperative immune recovery. *Heart Vessels*. 2021.
- Paparella D, et al. Cardiopulmonary bypass induced inflammation and management strategies. *J Card Surg*. 2019. Raja SG, et al. Inflammatory protection and immune support for cardiopulmonary bypass. *Cardiopulmonary Bypass*. 2023.
- Ranucci M, et al. Biocompatibility of cardiopulmonary bypass circuits and postoperative inflammatory response. *Perfusion*. 2016.
- Ricci D, et al. Systematic review comparing phosphorylcholine and polymer surface coatings in CPB. *Perfusion*. 2023.
- Saleem M, et al. Impact of biocompatible coated cardiopulmonary bypass circuits on platelet count. *Biol Clin Sci Res J*. 2023.

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- Seghatchian J, et al. Phosphorylcholine-based biomaterials and their applications in extracorporeal circulation systems. *Transfus Apher Sci.* 2017.
- Shetty T, et al. Narrative review on miniaturized extracorporeal technology and circuits in cardiac surgery. *The Cardiothoracic Surgeon.* 2025.
- Wahba A, et al. 2024 EACTS/EACTAIC/EBCP guidelines on cardiopulmonary bypass in adult cardiac surgery. *Eur J Cardiothorac Surg.* 2025.
- Warren OJ, et al. Systemic inflammatory response syndrome after cardiopulmonary bypass. *Eur J Cardiothorac Surg.* 2020.
- Yamamoto K, et al. Endothelial and leukocyte activation during CPB with phosphorylcholine-coated circuits. *Circ J.* 2020.
- Zangrillo A, et al. Clinical perspectives on inflammatory response during cardiopulmonary bypass. *J Cardiothorac Vasc Anesth.* 2024.