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ASSESSMENT EVALUATING CLINICAL OUTCOMES OF ALPHA STAT AND PH-STAT BLOOD GAS MANAGEMENT STRATEGIES DURING CARDIOPULMONARY BYPASS

Talia Arif[1], Huba Afzal[2], Syeda-Zaib-un-Nisa[3], Nabiha Noor[4], Dr. Yasir Ali Khan[5]

1. Clinical Cardiac Perfusionist at Sharif Medical City Hospital, Lahore.
Email: taliaarif57@gmail.com

2. Department of Allied Health Sciences, Superior University Lahore.

3. Department of Allied Health Sciences, Superior University Lahore.

4. Department of Allied Health Sciences, Superior University Lahore.

5. Consultant Cardiothoracic Surgeon, Sahiwal Institute of Cardiology, Sahiwal.
Email: dryasirkhan02@gmail.com

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Corresponding Author: *
taliaarif57@gmail.com

Abstract

Background: Cardiopulmonary bypass (CPB) constitutes a vital part of cardiac surgery which takes the place of heart and lung functions temporarily. Alpha-stat and pH-stat are blood gas management techniques, which are crucial in ensuring that there is an acid-base balance, cerebral perfusion and stability of physiological state during CPB.**Objective:** To evaluate clinical outcomes of alpha stat and pH-stat blood gas management strategies during cardiopulmonary bypass. **Methodology:** It was a descriptive analytical study that looked at 100 patients who underwent cardiac surgery using CPB. The sample involved children and adults. The demographics, anthropometrics, surgical variables, CPB parameters, blood gas and hemodynamic variables, and postoperative outcomes were determined. **Results:** The sample size (100 patients) was divided into two groups (alpha-stat (48) and PHstat (52) strategies). The two methods ensured that intraoperative hemodynamic and blood gas parameters were stable. Independent t-test revealed significant differences in CPB, pH, PaCO 2, MAP, PaO 2, the length of ventilation and length of stay ($p < 0.05$) but the cross-clamp time did not show significant differences. Alpha-stat was linked to reduced ventilation time and stay in hospital showing improved postoperative recovery.

Conclusions: Both alpha-stat and pH-stat approaches were useful in sustaining sufficient physiological parameters in case of cardiopulmonary bypass. Nonetheless, alpha-stat presented improved postoperative results, such as reduced ventilation time and hospitalization, which demonstrated increased

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recovery. Conversely, pH-stat was more applicable in pediatric patients since it has the benefit of improving cerebral perfusion.

INTRODUCTION

Cardiopulmonary bypass (CPB) is an essential component of cardiac surgery that temporarily replaces the functions of the heart and lungs, allowing surgeons to perform complex intracardiac procedures in a controlled and motionless environment. CPB induction involves systemic heparinization, cannulation of the great vessels, and gradual transition from native circulation to extracorporeal perfusion while maintaining adequate tissue oxygenation and perfusion (36). In adults, standardized CPB induction techniques are generally effective, although factors such as anticoagulation, cannula positioning, perfusion pressure, and venous return must be carefully monitored to avoid complications including hypotension, air embolism, and poor venous drainage (51).

In pediatric patients, especially neonates and infants, CPB induction is more challenging because of smaller blood volume, immature organ systems, and greater susceptibility to hemodilution and temperature fluctuations. These patients require reduced circuit volumes, smaller cannulae, and precise flow adjustments to ensure adequate perfusion and physiological stability during bypass (24).

Gas management during CPB is another critical aspect of perfusion practice. The oxygenator replaces pulmonary function by regulating oxygen delivery, carbon dioxide removal, and acid-base balance. Continuous monitoring of arterial oxygen tension (PaO_2), carbon dioxide tension ($PaCO_2$), and pH is essential to prevent complications such as hypoxia, hypercapnia, acidosis, or alkalosis that may adversely affect organ function, particularly the brain and heart (52). In adults, gas management generally aims to maintain normoxia and normocapnia, with adjustments guided by arterial blood gas analysis and patient comorbidities such as anemia, chronic lung disease, or cardiac dysfunction (57). Pediatric patients, however, present greater challenges due to higher metabolic rates and immature physiology, making them more vulnerable to rapid blood gas and acid-base fluctuations (48).

Different surgical and physiological conditions further influence gas management strategies during CPB. Procedures involving deep hypothermia or circulatory arrest require careful control of oxygen delivery and carbon dioxide levels to minimize neurological injury. Similarly, congenital cardiac surgeries may require individualized gas management because of altered systemic and pulmonary blood flow patterns (25). These considerations highlight the importance of tailored perfusion strategies according to patient age, temperature, and surgical complexity (7).

Blood gas management during CPB is primarily based on two strategies: alpha-stat and pH-stat management. Alpha-stat management maintains arterial pH and $PaCO_2$ at values measured at 37°C without temperature correction, thereby preserving intracellular electrical neutrality and cerebral autoregulation (15). In contrast, pH-stat management corrects blood gas values according to the patient's actual temperature and often involves the addition of carbon dioxide to maintain a pH of 7.40, resulting in cerebral vasodilation and increased cerebral blood flow (22).

These strategies have distinct physiological and clinical implications. Alpha-stat management is commonly preferred in adult cardiac surgery because it preserves cerebral autoregulation, reduces microembolic risk, and is associated with improved neurological stability and postoperative cognitive outcomes (13). However, during deep hypothermia, alpha-stat may lead to relatively reduced cerebral blood flow and uneven cerebral cooling (14). Conversely, pH-stat management promotes more uniform cerebral cooling and improved oxygen delivery, making it particularly useful in neonatal and pediatric cardiac surgery as well as deep hypothermic circulatory arrest (47). Despite these advantages, pH-stat may impair cerebral

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autoregulation and increase the risk of cerebral hyperperfusion and microembolic injury, especially in adults (15).

Recent studies have demonstrated varying outcomes associated with these strategies. pH-stat management has been shown to improve cerebral cooling and oxygenation during hypothermia but may increase embolic risk because of loss of autoregulation (46). Alpha-stat management, on the other hand, better preserves physiological acid-base balance and has been associated with reduced postoperative neurological dysfunction (56). Beyond neurological outcomes, acid-base strategies may also influence myocardial recovery, renal perfusion, and inflammatory responses during CPB (70).

In developing countries such as Pakistan, perfusion practices often depend on institutional preferences, perfusionist experience, and available equipment rather than standardized evidence-based protocols (9). Variations in CPB circuitry, oxygenator performance, and blood gas monitoring may further influence the effectiveness of alpha-stat and pH-stat management. Although modern automated systems can improve the precision of CO_2 and temperature regulation, their use remains limited in low-resource settings, increasing reliance on manual decision-making and perfusionist expertise (26).

Despite extensive international literature comparing alpha-stat and pH-stat strategies, there is limited evidence regarding their practical application and clinical outcomes in Pakistan. Existing studies indicate significant global variability in perfusion practice, emphasizing the need for consensus-based guidelines and standardized training (68). Therefore, this study aims to compare the clinical outcomes and decision-making preferences related to alpha-stat and pH-stat blood gas management among cardiac perfusionists in Pakistan. The findings may help identify practice variations, improve patient safety, and contribute toward the development of evidence-based national guidelines for CPB management.

METHODOLOGY

This cross-sectional study was conducted in the Department of Cardiac Surgery at a Sharif Medical City Hospital in Lahore over a period of four months. A total of 100 adult and pediatric patients undergoing open-heart surgery with cardiopulmonary bypass (CPB) were included. The sample size was calculated using a single population proportion formula based on a reference study, with a 95% confidence interval, 8% margin of error, and an estimated proportion of 20.4%. Non-probability consecutive sampling was used for patient selection. The study included adult and pediatric patients undergoing cardiac surgery requiring CPB and managed with either alpha-stat or pH-stat blood gas strategies. Patients with complete perioperative and postoperative clinical data, including oxygen administration, duration of mechanical ventilation, ICU stay, and clinical outcomes, were enrolled. Both elective and emergency cardiac surgery cases receiving standardized CPB were included. Patients undergoing procedures without CPB, redo surgeries, or those with incomplete clinical records, severe pre-existing neurological disorders, severe metabolic or acid-base abnormalities, or intraoperative death before completion of CPB were excluded.

A heart-lung machine with either a roller or centrifugal pump and membrane oxygenator was used for systemic perfusion and gas exchange during surgery. The CPB circuit included arterial and venous tubing, venous reservoir, heat exchanger, and filters. Temperature regulation was achieved using a built-in heat exchanger. Blood gas management followed institutional protocols, with arterial blood gases monitored periodically. Continuous intraoperative monitoring included electrocardiography, arterial blood pressure, central venous pressure, pulse oximetry, activated clotting time, urine output, and periodic blood gas analysis. Pump flow and pressure were adjusted according to patient size and clinical condition, and all equipment was calibrated according to institutional standards.

Preoperative, intraoperative, and postoperative imaging techniques were used to assess cardiac structure and function. Transthoracic echocardiography (TTE) was routinely performed, while transesophageal echocardiography (TEE) was used selectively during surgery for guidance and repair assessment. Postoperative evaluation included chest radiography and follow-up

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echocardiography, with computed tomography (CT) or magnetic resonance imaging (MRI) performed when required.

RESULTS

A total of 100 patients undergoing cardiopulmonary bypass (CPB) were included in the study, comprising equal proportions of pediatric and adult cardiac surgery patients (50% each). The majority of participants were aged 5–20 years (50%), followed by 41–60 years (29%) and 61–80 years (21%). Male patients constituted 58% of the study population, while females accounted for 42%. The mean body weight was 49.88 ± 27.58 kg, and the mean body surface area (BSA) was 1.39 ± 0.55 m^2, reflecting inclusion of both pediatric and adult patients.

Regarding blood gas management strategies, 52% of patients were managed with pH-stat and 48% with alpha-stat. Similarly, hypothermia was used in 52% of cases, while normothermia was used in 48%. The mean CPB duration was 107.45 ± 12.70 minutes, and the mean aortic cross-clamp time was 56.01 ± 31.03 minutes.

Blood gas and hemodynamic parameters remained within acceptable clinical ranges during CPB. The mean pH was 7.35 ± 0.02, $PaCO_2$ was 44.98 ± 3.97 mmHg, MAP was 65.54 ± 5.83 mmHg, and PaO_2 was 233.55 ± 19.62 mmHg, indicating adequate perfusion and oxygenation during bypass.

Postoperative outcomes were generally favorable. The mean duration of mechanical ventilation was 12.57 ± 2.65 hours, while the mean hospital stay was 8.12 ± 1.40 days. More than half of the patients (54%) experienced no postoperative complications. Bleeding was the most common complication (28%), followed by arrhythmias (18%).

A statistically significant association was observed between type of surgery and blood gas management strategy ($\chi^2 = 23.07$, $p < 0.001$). Most pediatric patients were managed with pH-stat (76%), whereas alpha-stat was predominantly used in adult patients (72%).

Independent sample t-test analysis demonstrated significant differences between alpha-stat and pH-stat groups for CPB time ($p = 0.049$), pH ($p < 0.001$), $PaCO_2$ ($p < 0.001$), MAP ($p < 0.001$), PaO_2 ($p < 0.001$), ventilation duration ($p < 0.001$), and hospital stay ($p < 0.001$). No significant difference was observed for cross-clamp time ($p = 0.597$). Patients managed with alpha-stat showed shorter ventilation duration and hospital stay compared to the pH-stat group.

Table 1: Demographic and Anthropometric Characteristics

Variable	Category / Measure	Frequency (%) / Mean ± SD
Age Group (Years)	5–20 years	50 (50.0%)
	41–60 years	29 (29.0%)
	61–80 years	21 (21.0%)
Gender	Male	58 (58.0%)
	Female	42 (42.0%)
Weight (kg)	Mean ± SD	49.88 ± 27.58
Body Surface Area (m^2)	Mean ± SD	1.39 ± 0.55

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Figure 1: Age Distribution of Study Participants

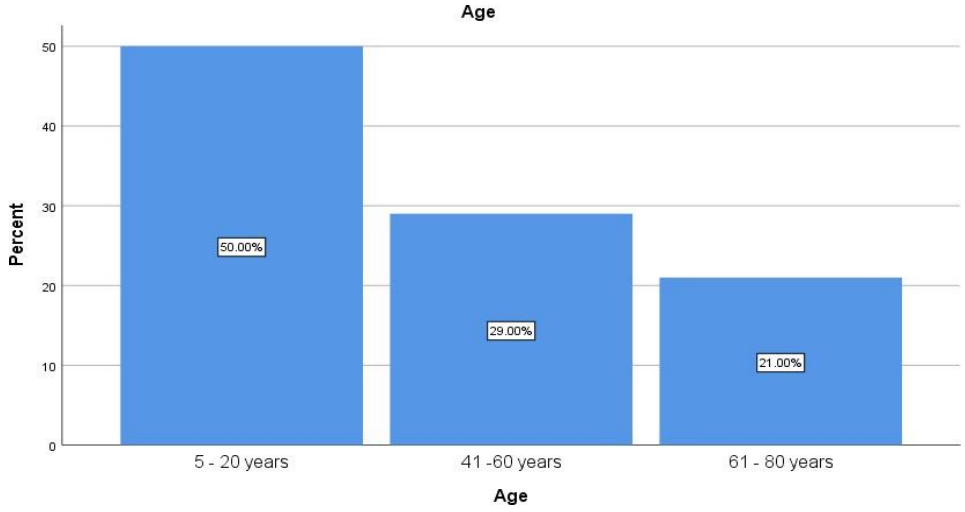

Figure 2: Gender Distribution

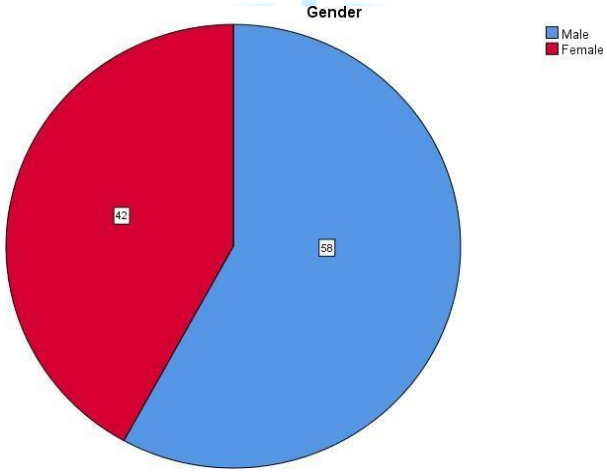

Table 2: Surgical and Cardiopulmonary Bypass (CPB) Characteristics

Variable	Category / Measure	Frequency (%) / Mean ± SD
Type of Surgery	Pediatric cardiac surgery	50 (50.0%)
	Adult cardiac surgery	50 (50.0%)
Blood Gas Strategy	Alpha-stat	48 (48.0%)
	pH-stat	52 (52.0%)
Temperature Strategy	Hypothermia	52 (52.0%)
	Normothermia	48 (48.0%)
CPB Time (minutes)	Mean ± SD	107.45 ± 12.70
Cross-Clamp Time (minutes)	Mean ± SD	56.01 ± 31.03

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Figure 3: Distribution of Blood Gas Management Strategies

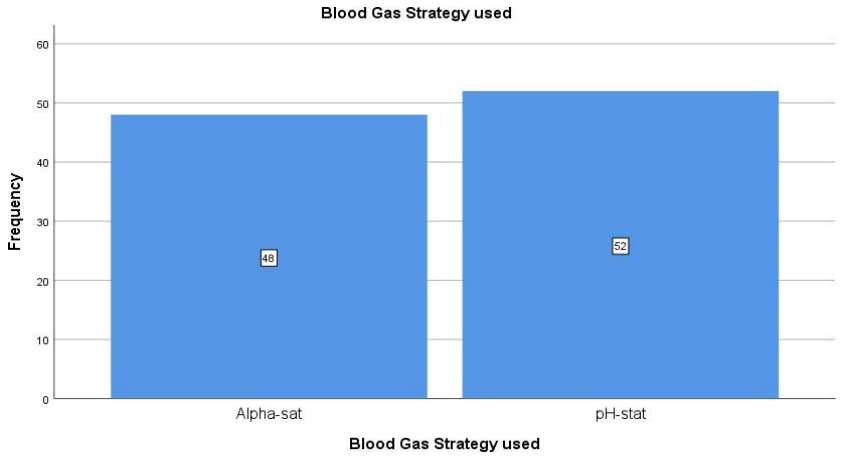

Figure 4: CPB Time Distribution

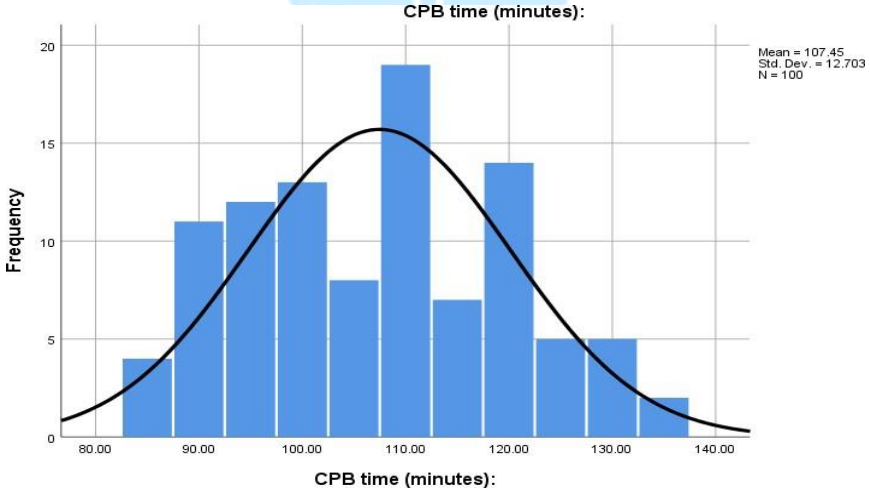

Table 3: Blood Gas and Hemodynamic Parameters

Variable	Mean	Std. Deviation
pH	7.35	0.02
$PaCO_2$ (mmHg)	44.98	3.97
MAP (mmHg)	65.54	5.83
PaO_2 (mmHg)	233.55	19.62

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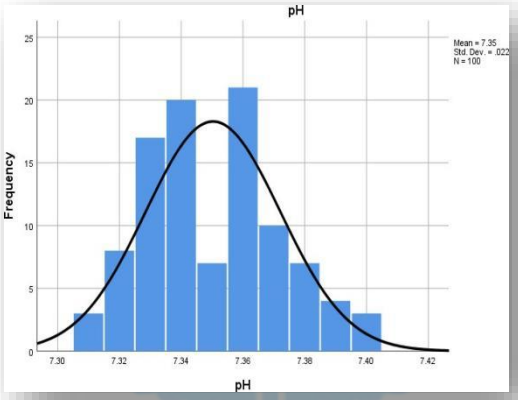
Figure 5: Intraoperative blood gas and hemodynamic parameters during cardiopulmonary bypass (CPB), demonstrating maintained physiological stability throughout the procedure.

The average pH was 7.35 +/-0. 02, which is a slightly acidic yet clinically normal range of pH during CPB. Such slight change in pH is anticipated with the physiological alterations of extracorporeal circulation. The average of the PaCO 2 was 44.98 +/- 3.97 mmHg that is marginally greater than the normal body physiological level, indicating the effect of pH-stat management, whereby carbon dioxide is injected to control the pH in case of hypothermia.



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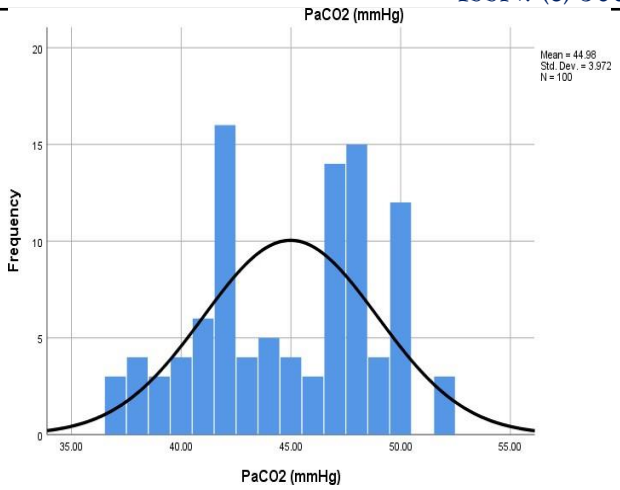

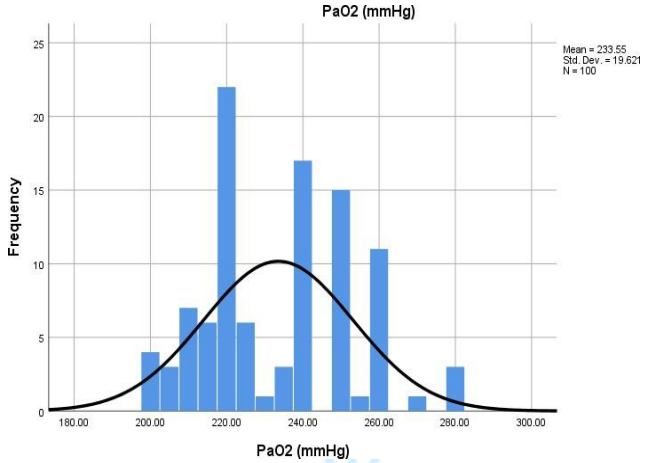

Histogram of MAP Parameters

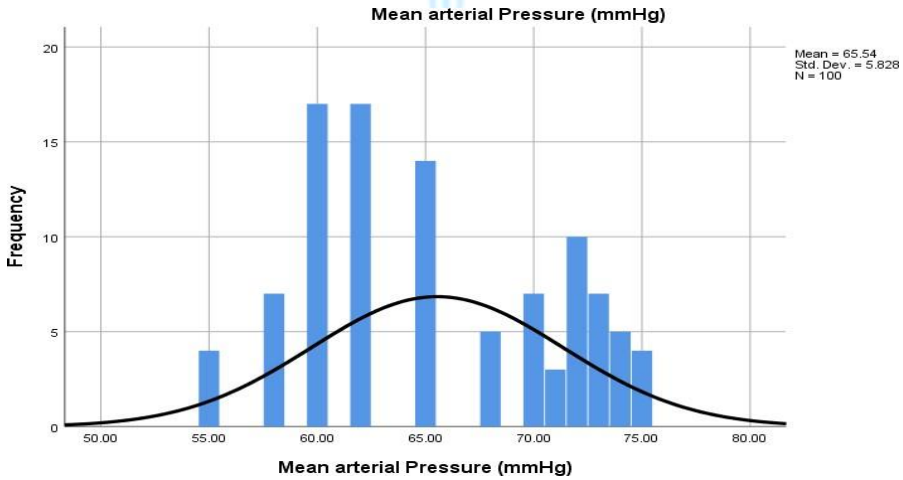

Table 4: Postoperative Outcomes

Variable	Category / Measure	Frequency (%) / Mean ± SD

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Ventilation Duration (hours)	Mean ± SD	12.57 ± 2.65
Hospital Stay (days)	Mean ± SD	8.12 ± 1.40
Postoperative Complications	None	54 (54.0%)
	Bleeding	28 (28.0%)
	Arrhythmia	18 (18.0%)

Figure 6: Postoperative Complications

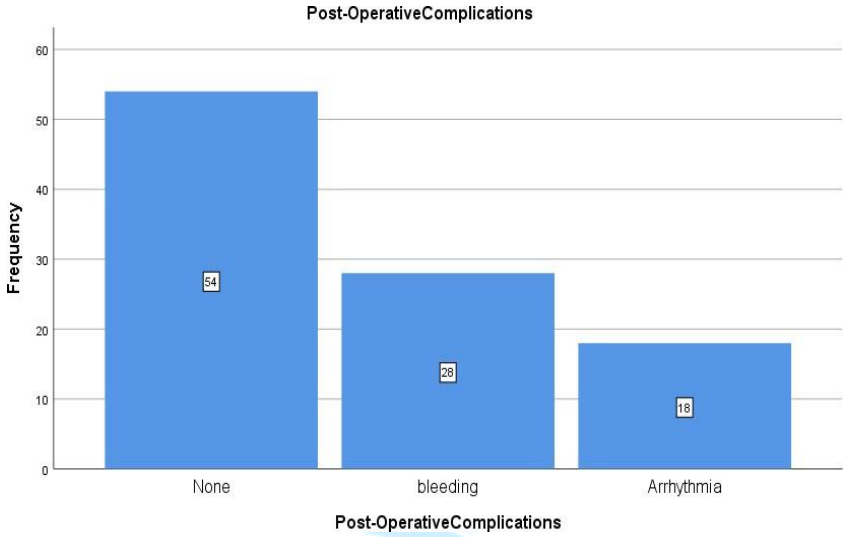

Table 5: Association Between Congenital Heart Surgeries and Blood Gas Strategy

Congenital Heart Surgery Blood Gas Strategy used Crosstabulation				
		Blood Gas Strategy used		Total
		Alpha-sat	pH-stat	
Congenital Heart Surgeries	Pediatric open-heart surgery	12	38	50
	Adult open-heart surgery	36	14	50
Total		48	52	100
X_2 = 23.07, 1, p < 0.001).				

Description of Independent Sample t-Test Analysis.

There was a statistically significant association between type of surgery and blood gas management strategy, with pH-stat predominantly used in pediatric patients and alpha-stat more commonly used in adult patients

Table 6: Comparison Between Alpha-stat and pH-stat Groups

Variable	Alpha-stat Mean ± SD	pH-stat Mean ± SD	t-value	p-value
Cross-clamp time (min)	54.29 ± 32.09	57.60 ± 30.23	-0.530	**0.597**

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CPB time (min)	110.04 ± 11.86	105.06 ± 13.08	1.989	**0.049***
pH	7.365 ± 0.017	7.337 ± 0.015	8.486	**<0.001***
$PaCO_2$ (mmHg)	42.35 ± 3.53	47.40 ± 2.57	-8.209	**<0.001***
MAP (mmHg)	68.87 ± 4.45	62.46 ± 5.24	6.563	**<0.001***
PaO_2 (mmHg)	221.66 ± 14.95	244.51 ± 16.89	-7.137	**<0.001***
Ventilation duration (hrs)	10.91 ± 1.80	14.09 ± 2.38	-7.461	**<0.001***
Hospital stay (days)	7.33 ± 1.05	8.84 ± 1.28	-6.382	**<0.001***

***Statistically significant at $p \leq 0.05$.**

An independent sample t-test was used to compare the mean values of continuous variables between the alpha-stat and pH-stat groups. A p-value ≤ 0.05 was considered statistically significant, indicating a meaningful difference between the two groups.

DISCUSSION

This study evaluated the effects of alpha-stat and pH-stat blood gas management strategies during cardiopulmonary bypass (CPB) in combined pediatric and adult cardiac surgery patients. The findings demonstrated stable physiological parameters, effective perfusion management, and generally favorable postoperative outcomes, consistent with previous literature.

The wide age range and variability in body weight and body surface area reflected inclusion of both pediatric and adult populations, increasing the clinical applicability of the findings. Similar observations have been reported in previous CPB studies, where body size significantly influenced perfusion flow rates and metabolic requirements during bypass (18,45).

A significant association was observed between type of surgery and blood gas management strategy ($p < 0.001$), with pH-stat predominantly used in pediatric patients and alpha-stat more commonly used in adults. These findings are consistent with studies reporting improved cerebral perfusion with pH-stat in pediatric hypothermic CPB, while alpha-stat better preserves cerebral autoregulation in adults (62,63).

The mean CPB duration and cross-clamp times were within ranges reported in previous cardiac surgery studies (58,64). Slightly higher use of hypothermia in this study aligns with evidence supporting its role in reducing metabolic demand and providing organ protection during CPB (19). Blood gas and hemodynamic parameters, including pH, $PaCO_2$, MAP, and PaO_2, remained within acceptable clinical ranges, indicating adequate acid-base control, oxygenation, and tissue perfusion throughout bypass (20,66).

Postoperative outcomes were favorable, with relatively short ventilation duration and hospital stay, suggesting effective perioperative and postoperative management. More than half of the patients experienced no complications, while bleeding and arrhythmias were the most common adverse events, findings consistent with existing CPB literature (40,43,44).

The current findings further support previous evidence that both alpha-stat and pH-stat strategies can achieve satisfactory physiological stability and postoperative outcomes when applied appropriately according to patient characteristics. Studies have demonstrated improved cerebral oxygenation with pH-stat in pediatric patients, whereas alpha-stat remains beneficial in adults due to preservation of

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autoregulation and reduced embolic risk (31,54,60). Similarly, previous research has shown that optimized CPB management and close perioperative monitoring contribute significantly to improved recovery and reduced complications regardless of the blood gas strategy employed (8,33,37).

Overall, the study suggests that both alpha-stat and pH-stat management strategies are clinically effective during CPB when individualized according to patient age, physiology, and surgical requirements. These findings emphasize the importance of tailored perfusion management to optimize outcomes in cardiac surgery patients.

CONCLUSION

Both alpha-stat and pH-stat approaches were useful in sustaining sufficient physiological parameters in case of cardiopulmonary bypass. Nonetheless, alphastat presented improved postoperative results, such as reduced ventilation time and hospitalization, which demonstrated increased recovery. Conversely, pH-stat was more applicable in pediatric patients since it has the benefit of improving cerebral perfusion. Thus, the strategy selection must be personalized, depending on the patient features and clinical needs.

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