

**Comparison of capnography and arterial blood gases for
prediction of early Extubation patients undergoing
coronary artery bypass graft surgery**



SUPERIOR UNIVERSITY

Thesis Submitted to

The Superior University, Lahore

In Partial Fulfillment of the

Requirement for the Degree of

Master of Science in Allied Health Sciences

By

Amad Khan

SU91-MSAHW-S24-042

Session: 2024-2026

Faculty of Allied Health Sciences

**Comparison of capnography and arterial blood gases for
prediction of early Extubation patients undergoing coronary
artery bypass graft surgery**



SUPERIOR UNIVERSITY

Thesis Submitted to

The Superior University, Lahore

In Partial Fulfillment of the

Requirement for the Degree of

Master of Science in Allied Health Sciences

By

Amad Khan

Roll No. SU91-MSAHW-S24-042

Session: 2024-2026

Faculty of Allied Health Sciences

Author's Declaration

I hereby state that my MS thesis titled “**Comparison of capnography and arterial blood gases for prediction of early Extubation patients undergoing coronary artery bypass graft surgery**” is my work and has not been submitted previously by me for taking any degree from this University,

The Superior University, Lahore,

or anywhere else in the country/world.

At any time if my statement is found to be incorrect even after my graduation, the university has the right to withdraw my MS/M.Phil. degree.

Amad Khan

Date: _____

Plagiarism Undertaking

I solemnly declare that the research work presented in the thesis titled “**Comparison of capnography and arterial blood gases for prediction of early extubation patients undergoing coronary artery bypass graft surgery**” is solely my research work with no significant contribution from any other person.

Small contributions/help wherever it was taken has been duly acknowledged, and that complete thesis has been written by me.

I understand the zero-tolerance policy of the HEC and University,

The Superior University, Lahore,

towards plagiarism. Therefore, I, as the author of the above-titled thesis, declare that no portion of my thesis has been plagiarised and any material used as a reference is properly referred to/cited. I undertake that if I am found guilty of any formal plagiarism in the above-titled thesis, even after the awarding of an MS/M.Phil. degree, the university reserves the right to withdraw/revoke my MS/M.Phil. degree and that HEC and the university have the right to publish my name on the HEC/university website on which names of students are placed who submitted a plagiarized thesis.

Student/Author Signature: _____

Amad Khan

Research Completion Certificate

This is to certify that the thesis entitled "**Comparison of capnography and arterial blood gases for prediction of early extubation patients undergoing coronary artery bypass graft surgery**" submitted by "**Amad Khan**" has been accepted towards the partial fulfilment of the requirement for "**MS Allied Health Sciences**". The quality of the work contained in this thesis is adequate for the award of a degree.

Signature: _____

Dr Sarmad Siddique
Faculty of Allied Health and Medical Science,
Superior University, Lahore.

Certificate of Approval

This is to certify that the research work presented in this thesis, titled “**Comparison of capnography and arterial blood gases for prediction of early Extubation patients undergoing coronary artery bypass graft surgery**”, was conducted by “**Amad Khan**” under the supervision of “**Dr Sarman Siddique**”

No part of this thesis has been submitted anywhere else for any other degree. This thesis is submitted to the Faculty of Allied Health Sciences, The Superior University, Lahore, in partial fulfilment of the requirements for the degree of Master of Science in the field of “**Allied Health Sciences**” in the Faculty of Allied Health Sciences at The Superior University, Lahore.

Amad khan

Signature: _____

Examination Committee:

Session Chair:

Signature: _____

a) External Examiner:

Signature: _____

b) Internal Examiner:

Signature: _____

c) Dr Chanda Naseem:

Signature: _____

d) PL/HOD: Dr Hafiz Shehzad

Signature: _____

e) Dean: Prof. Dr M. Naveed Babur

Signature: _____

f) Controller of Examination: Dr M. Haris

Signature: _____

DEDICATION

This thesis is dedicated to my parents, whose unwavering support, unconditional love, and constant encouragement have been the foundation of my journey. Your sacrifices and belief in me have been my greatest strength.

To my family, thank you for being my pillars of support, for celebrating my successes, and for standing by me in times of struggle. Your presence has made this achievement all the more meaningful.

I am deeply grateful to each of you for inspiring me to reach higher and pursue my dreams.

ACKNOWLEDGEMENT

In the name of Allah, the most Gracious, the most Merciful.

I am extremely thankful to Almighty 'Allah', Who is the entire resource of knowledge and wisdom endowed to mankind, for providing me with the acumen and vision to complete this endeavour.

I would like to express my profound gratitude to my supervisor for his wise counsel and encouraging attitude towards this study. I am extremely grateful to him for immensely facilitating me during my study period by ensuring the provision of favourable circumstances and a conducive environment. This project would not have been possible without his support and expert guidance.

In the end, I would like to extend my deepest gratitude to my family members. Without their encouragement, I would not have been able to complete this endeavour.

Amad Khan

TABLE OF CONTENTS

CERTIFICATE OF APPROVAL	5
DEDICATION	6
ACKNOWLEDGEMENT	7
LIST OF TABLES	9
LIST OF FIGURES	10
LIST OF ABBREVIATIONS	11
ABSTRACT	12
CHAPTER 1	13
INTRODUCTION	13
RATIONALE OF STUDY	17
OBJECTIVES	18
CHAPTER 2	19
LITERATURE REVIEW	19
CHAPTER 3	26
METHODOLOGY	26
3.1. RESEARCH DESIGN	26
3.2. CLINICAL SETTINGS	26
3.3. SAMPLE SIZE	26
3.4. SAMPLING TECHNIQUE	26
3.5. DURATION OF STUDY	26
3.6. SELECTION CRITERIA	26
3.6.1. <i>Inclusion Criteria</i>	26
3.6.2. <i>Exclusion Criteria</i>	26
3.7. ETHICAL CONSIDERATION	27
3.8. DATA COLLECTION PROCEDURE	27
3.9. DATA ANALYSIS	31
CHAPTER 4	32
RESULTS	32
CHAPTER 5	42
DISCUSSION	42
CONCLUSION	49
RECOMMENDATION	50
LIMITATION	51
REFERENCES	52
APPENDICES	59
APPENDIX-1	59
Ethical Approval Letters	59

APPENDIX-2.....	62
Informed Consent.....	62
<i>URDU VERSION</i>	64
APPENDIX-3.....	66
<i>QUESTIONNAIRE</i>	66

LIST OF TABLES

Table No.	Description	Page
Table 4.1	Demographic and Comorbidity Characteristics of Patients Undergoing CABG (N = 70).....	20
Table 4.2	Intraoperative Characteristics (Mean $\pm$ SD), Clinical.....	21
Table 4.3	Arterial Blood Gas (ABG) Parameters at Baseline, Trigger, Extubation, and Post-Extubation.....	22
Table 4.4	Hemodynamic Parameters at Baseline, Trigger, Extubation, and Post-Extubation	24
Table 4.5	Outcomes of Early Extubation and Postoperative Outcomes.....	25
Table 4.6	Early Extubation by Group with Ejection Fraction and Smoking Status.....	26
Table 4.7	Group Comparison of PaCO ₂ and pH Categories at Extubation.....	27
Table 4.8	Intraoperative Outcomes by Group (ICU Stay, Alarms, and Manipulations – Extended Analysis).....	28
Table 4.9	Multivariate Logistic Regression Analysis of Early Extubation (<6 Hours) Predictors.....	29

LIST OF FIGURES

Figure No.	Description	Page
Figure 4.1	Difference in pH and PaCO ₂ Across Timepoints (Capnography vs ABG).....	20
Figure 4.2	SpO ₂ , Heart Rate, Respiratory Rate, and Systolic Blood Pressure Across Different Timepoints.....	22

LIST OF ABBREVIATIONS

Abbreviation	Full Form
ABG	Arterial Blood Gas
CABG	Coronary Artery Bypass Graft
EtCO ₂	End-Tidal Carbon Dioxide
PaCO ₂	Partial Pressure of Arterial Carbon Dioxide
PaO ₂	Partial Pressure of Arterial Oxygen
SpO ₂	Peripheral Oxygen Saturation
FiO ₂	Fraction of Inspired Oxygen
pH	Potential of Hydrogen
HCO ₃ ⁻	Bicarbonate
BE	Base Excess
RR	Respiratory Rate
HR	Heart Rate
BP	Blood Pressure
MAP	Mean Arterial Pressure
ICU	Intensive Care Unit
MV	Mechanical Ventilation
V _t	Tidal Volume
PEEP	Positive End-Expiratory Pressure
CPB	Cardiopulmonary Bypass
ECG	Electrocardiogram
CI	Cardiac Index
CO	Cardiac Output
SD	Standard Deviation
ROC	Receiver Operating Characteristic
AUC	Area Under the Curve
PPV	Positive Predictive Value
NPV	Negative Predictive Value

ABSTRACT

Background: Early extubation of the ICU after coronary artery bypass graft (CABG) surgery improves recovery and the length of stay. Capnography is a noninvasive device, which is applied to identify the appropriateness of extubation, but its predictability against arterial blood gases (ABGs) is unclear.

Methods: This study used 70 random postoperative CABG patients to be divided into capnography (n=35) and ABG (n=35) groups. At baseline, trigger, extubation and post-extubation, demographics, comorbidities, ventilatory, arterial blood gas and haemodynamic parameters were recorded. Between-group comparisons were done using t-tests and chi-square tests with 95% confidence intervals (CI). To determine independent predictors of early extubation, logistic regression was used.

Results: Mean time to extubation was significantly shorter in the capnography group (180 ± 40 min) versus the ABG group (230 ± 60 min; mean difference -50 min, 95% CI -76 to -24 ; $p < 0.001$). Early extubation occurred in 28/35 (80.0%) patients in the capnography group versus 22/35 (62.9%) in the ABG group ($p = 0.186$). Capnography patients had lower PaCO₂ at extubation (41.2 ± 5.5 mmHg vs 44.8 ± 6.1 mmHg; mean difference -3.6 mmHg, 95% CI -6.4 to -0.8 ; $p = 0.012$) and higher pH (7.38 ± 0.04 vs 7.35 ± 0.05 ; mean difference 0.03 , 95% CI 0.01 – 0.05 ; $p = 0.007$). They also experienced fewer alarms (1.8 ± 1.0 vs 3.1 ± 1.4 ; mean difference -1.3 , 95% CI -1.9 to -0.7 ; $p < 0.001$), fewer manipulations (2.2 ± 1.1 vs 3.0 ± 1.5 ; mean difference -0.8 , 95% CI -1.4 to -0.2 ; $p = 0.013$), and shorter ICU stays (2.1 ± 0.8 vs 2.8 ± 1.1 days; mean difference -0.7 , 95% CI -1.1 to -0.3 ; $p = 0.003$). Logistic regression identified the capnography group (AOR 3.06; 95% CI 1.10–8.47; $p = 0.031$), normal PaCO₂ (AOR 2.67; 95% CI 1.01–7.02; $p = 0.047$), low alarms (AOR 3.18; 95% CI 1.21–8.29; $p = 0.019$), and short ICU stay (AOR 4.38; 95% CI 1.52–12.65; $p = 0.006$) as independent predictors of early extubation.

Conclusion: Capnography is more effective than ABG in predicting early extubation after CABG surgery. It reduces time to extubation, improves ventilation parameters, minimises alarms and manipulations, and is an independent predictor of successful early extubation.

Keywords: Capnography; Arterial Blood Gas Analysis; Early Extubation; Coronary Artery Bypass Grafting; CABG; Mechanical Ventilation; End-Tidal Carbon Dioxide; Respiratory Monitoring; Cardiac Surgery; Extubation Prediction.

Chapter 1

INTRODUCTION

There is a major spread in the number of publications related to capnography, namely continuous end-tidal carbon dioxide (ETCO₂) monitoring, in the last three decades. This has been in tandem with an increment in the number of patients who have applications to use this device. It is important to mention that capnography has already been explored in terms of intubation and cardiopulmonary resuscitation (CPR) and proved to be beneficial to patients and providers (1). In intubation, capnography is the surest way of confirming the presence of an endotracheal tube (ETT) in the trachea. It can also identify ETT dislodgement and possibly decrease the rate of accidental hypo- and hyperventilation. Capnography, an indicator of early realization of restoration of spontaneous circulation (ROSC), could be useful in mortality prediction. It may be related to the blood circulation in the lungs, which is the reflection of the effectiveness of the chest compressions in CPR (2). In 2010, the scientific guidelines of Adult and Paediatric Advanced Life Support were improved by the International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care to include the use of capnography during those critical events as per the growing body of evidence (4). The new guidelines promoted the standardized use of quantitative waveform capnography during intubation and CPR. Capnography was classified as a level I recommendation for any hospital setting because it is reliable in ensuring that the ETT is in the right position. Capnography can potentially improve the quality of chest compressions, and this may result in a measure of successful compressions and reduce interruptions due to the detection of ROSC without having to pause regularly to check pulse during CPR (Class IIa). These guidelines have just been published, and it remains unknown whether they are being applied to children. Overall, not a great abundance of evidence underlies the application of capnography to minors, especially in the emergency department (ED) (5, 6). This is due to the direct effects of the underlying changes in the perioperative care systems, extracorporeal perfusion, anaesthesia, and surgery on the improvement of the postoperative outcome (1-2). The concept of fast-track cardiac care or early extubation was first described by Prakash et al. (3). This term is used to refer to the complex interventions which comprise the early extubation, anaesthetic care, mobilisation, and discharge of patients in hospital. These interventions are aimed at the reduction of the length of hospital stay, length of stay in

intensive care unit, perioperative morbidity, and cost. To reduce the risk of respiratory complications, mechanical ventilation, tracheal endotracheal tubes, and other risk factors, which include age and other thoracic surgery methods, are used (1, 4-8). Most of the fast-track protocols were aimed at maximising the length of stay (LOS) and lowering the total expenses of the patients undergoing coronary artery bypass graft (CABG) operations. This was achieved through the stress on the significance of early and rapid removal of the vent tubes in the surgical intensive care unit (SICU) (9-13). The Society of Thoracic Surgeons (STS) defines early extubation as a time point that is less than 6 hours and prolonged intubation as a time point that is more than 24 hours (14-17). Consideration of the further reflection on early extubation is conditional upon the avoidance of the negative consequences of the late one, along with any further costs (18-19). However, the heterogeneity of cardiac surgery patients has restricted the effectiveness of the practices and risk prediction protocols that were previously suggested. The rate of complication and the period in CABG (11) are much greater, and this is somewhat confusing. Most of the study population (123 of 142 adult patients) had fast-track cardiac care within one hour of or at the time of open-heart surgery, which had been performed within three hours of surgery of the patient (3). Patients with a reduction in their cardiac index and ventricular filling pressures and receiving a low amount of fluid were the most appropriate candidates in this approach (20). Extubation was done immediately on five out of the 36 patients, and an average of six hours was taken by the other patients. Evidence of successful extubation eight hours after surgery has been given by other researchers (21-22). In another study, the most appropriate candidates with early extubation included haemodynamically stable patients, those with an alveolar-arterial gradient of less than 150 mmHg, with excellent donor liver functioning, and without encephalopathy (4). The application of all levels of care within the first 48 hours of liver transplantation resulted in a decrease in the time to extubation and LOS within the ICU and no alterations to the intraoperative procedures and personnel (4). Accelerated cardiac rehabilitation is an intervention that is multifaceted. The combination of the cardiac anaesthesia care with the postoperative care, namely, early extubation after surgery, was also called 'fast-track cardiac care' to reduce the hospital expenses and length of stay (5-6). The application of high-dose opioid-based Anaesthesia has been applied in the conventional cardiac surgery care environment (no fast track) and in the ICU overnight mechanical ventilation just after

the surgery (2). However, the new fast-track care units also apply the mechanical breathing support during cardiac surgery or within hours of surgery, as the time-based guidelines imply that the breathing support needs to be withdrawn in case of an unavoidable breathing failure. What is the evidence? During another study, McCarter et al. (n=634) established that capnography was more useful than pulse oximetry in identifying cases of respiratory depression in postoperative patients undergoing supplemental oxygen delivery. It was found that this breath-by-breath monitoring is more accurate in predicting the need for intervention (17). In line with the American Society of Anaesthesiologists' (ASA) standards of basic anaesthetic monitoring that were updated in 2010, there is a need to have adequate ventilation by qualitative clinical assessment and monitoring of expired carbon dioxide during general anaesthesia and moderate/deep sedation. This is an intervention that has been partly embraced because of the risk of procedural sedation and dictates the monitoring of the carbon dioxide that has already been expelled as a measure of ensuring the ventilation required (18). Surrogates do not always define the adequacy of ventilation, e.g., respiratory rate. A capnometer can quantitatively measure respiratory rate and availability of exhaled carbon dioxide, but it does not give a report on tidal volume. It should have carbon dioxide, whether at the site or in the form of anaesthesia given, and this depends on the extent of sedation, either moderate or profound. We would submit that a similar degree of vigilance is needed in the postoperative setting; most of the patients are still anaesthetised, especially patients who are highly prone to respiratory instability (19). Capnography was found to have better rates of detection of respiratory depression in a small randomised prospective study of 54 opioid-naïve postoperative orthopaedic patients. These findings led the authors to conclude that the use of capnography could be more suitable among high-risk post-surgical patients in a general care nursing unit who are under opioid therapy. This technology also raises the issue of appropriate and consistent positioning of end-tidal CO₂ surveillance apparatus in awake patients during extubation, patient comfort, and the familiarity of the nursing staff with this device as opposed to pulse oximetry. Patient and nursing education can solve these problems (20). Finally, the central goals of most of the policy changes are to minimize health care spending and improve the safety of patients. The topic of postoperative respiratory events has been recently reintroduced into the limelight because of the new technological changes in the perioperative

setting, which have facilitated the introduction of more monitoring. Our view is that the use of postoperative capnography in the postoperative unit is necessary to ensure that the end-tidal CO₂ is consistently monitored, as well as the timely detection of the calamitous respiratory events, since pulse oximetry has become the standard of care in many settings other than the operating room (1).

RATIONALE OF STUDY

Fast-track extubation (FTE) is an urgent method of enhancing recovery, decreasing the intensive care unit (ICU) stay duration, and saving on healthcare costs in patients undergoing coronary artery bypass graft (CABG) surgery. However, patient safety and early extubation must be highly balanced, especially when it comes to the provision of optimal ventilation and oxygenation. Capnography and pulse oximetry are non-invasive devices that offer real-time information on the respiratory status of a patient. Capnography is used to measure end-tidal carbon dioxide (EtCO₂), a measure of adequate ventilation, and pulse oximetry to assess arterial oxygen saturation (SpO₂). The integration of the two modalities throughout and following surgery can enhance clinical decision-making because it allows the detection of respiratory compromise earlier and safer extubation. There is little information on their usage together in the facilitation of FTE in patients undergoing CABG procedures, despite them being common in anaesthesia and critical care. As such, the aim of this randomised clinical trial was to ascertain the possibility of pulse oximetry and capnography utilization together to amplify the safety and fast-track extubation scheduling in this vulnerable surgical group.

OBJECTIVES

- To assess whether the combined use of capnography and pulse oximetry improves the timing and safety of fast-track extubation in patients undergoing CABG surgery.
- To compare postoperative outcomes, including extubation time and respiratory complications, between patients monitored with and without these modalities.

Chapter 2

LITERATURE REVIEW

Fast track extubation (FTE) is a generally accepted technique of discharge of patients under mechanical ventilation (MV) following the coronary artery bypass graft (CABG) surgery. Mechanical ventilation is normally given to the patients undergoing cardiac surgery at the rates of 1-6 hours. The specific effects of prolonged mechanical ventilation are infection, atelectasis, and mortality increase (1, 2). The efficient situation management and the endotracheal tube extension would minimise the challenges and the cost (1, 3). FTE can save a healthcare cost by approximately 50 per cent of the cost post-surgery CABG surgery (4). Through the aid of a suitable anaesthetic strategy for the surgery and aftercare treatment, it becomes possible to introduce FTE to patients undergoing CABG without any major complications (5).

Arterial blood gas (ABG) analyses are widely used in order to assess the preparedness of patients to stop. ABG testing is the conclusive measure that is used to identify the presence or absence of oxygenation and ventilation during the postoperative mechanical ventilation (MV) (6). In the operating rooms and the intensive care units, arterial line cannulation facilitates continuous and real-time monitoring of the systemic blood pressure, blood gas analysis, and various laboratory tests. Nevertheless, it is indicated that there are some risk factors involved in this process (7). An arterial line introduction over 48 or 72 hours is an intrusive surgery, which correlates with diverse outcomes, including contagiousness, local haematoma, vascular pain, thrombosis, disseminated intravascular coagulation, and poor cardiac output (8-10). Iran, a developing country with sanctions, on the other hand, cannot make use of advanced medical equipment, including ABG analyzers. Consequently, it will be wise to find a non-invasive alternative method of alleviating these problems and enhancing accessibility (2).

Pulse oximetry has always been recognised as a non-invasive and valid technique of determining oxygenation by the public (11). In many conditions, pulse oximetry is the only standard used to measure oxygenation and institute changes regarding oxygenation in mechanical ventilation. Also, capnography is prescribed in numerous clinical situations (12). The concept of measuring the concentration of carbon dioxide (CO₂) in the emitted air through the infrared light is referred to as capnography. The outputs of this non-invasive CO₂ assessment technique are applied to understand the

nature of the ventilation (efficiency of the CO₂ elimination), perfusion (carrying of the CO₂ into the bloodstream), and metabolism (producing of CO₂ by the body cells) among intubated and free-ventilating patients (13, 14). Capnography is the treatment of choice in certain situations, e.g., when the exact location of the endotracheal tube should be ascertained (15). However, in certain situations, the present data is marked by a significant number of inconsistencies, including MV parameter adjustment and cardiac resuscitation, and no similar recommendations are provided (16-18). Other studies have proven that the variables are not correlated and that the difference between the two is high (19). Conversely, other studies have advocated equal importance of the two to each other in the measurement of the CO₂ levels (3).

Anaesthesia and surgery, extracorporeal perfusion, and perioperative care have been improved greatly, and this has greatly contributed to the quality of postoperative outcomes in medicine. However, the problem of respiratory complications during post-cardiac surgery is also widespread, and they are mainly attributed to the thoracic surgical method, the problem of tracheal intubation, mechanical ventilation, and other risk factors, including age (4).

Long-controlled respiration has been a convention in cardiac surgery mainly because of the use of high-dose narcotic anaesthesia and fears of myocardial ischaemia in the initial postoperative phase. The improvement of rationalisation of the use of resources is the main cause of the growing popularity of the fast-track extubation (FTE) techniques. Recent articles indicate that the early extubation (less than 8 hours) after cardiac surgery is properly represented (14), which might be cost-effective (15, 16) and even beneficial (13) in addition. One can also note a decrease in postoperative spending which is mainly attributed to the decrease in the use of the intensive care unit (ICU) as well as length of stay (LOS) (13, 17). However, the threats of immediate or very early extubation after the operation are also a contention or grey area, and the authors have taken different timestyles of early extubation depending on their approaches and experiences (5).

Techniques of anaesthesia have changed in line with the progress in cardiovascular surgery. Rapid track (FT) extubation was the first idea that was introduced in the field of anesthesia some 40 years ago and is regarded as one of the most important developments in the sphere of anaesthesia care. The effectiveness of this method of extubation is assessed in a variety of studies, and it is proven to provide better

recovery, avoid negative consequences, save resources, and decrease the cost of heart surgery without causing negative effects on patients (7).

Operative room extubation is now termed ultra-fast track (UFT) and has ended up being a term that inevitably led to the decrease in the mechanical breathing time of many organisations. Nevertheless, in the light of the fact that there is some evidence to suggest that such a method enhances the workflow in the care process and shortens the duration of stay in the hospital and the intensive care unit (ICU) without requiring postoperative complications, a universal protocol is lacking to guide UFT in cardiovascular surgery patients. It, therefore, remains a controversial procedure and is mainly used in a very selective group of patients and operations (5).

Some of the benefits of early extubation include reduced time of stay in an intensive care unit and hospital and cost (1-4). Numerous research projects have been done to enhance the success of the management of CABG patients. A study at the Society of Thoracic Surgeons Adult Cardiac Surgery Database (STS ACSD) has indicated that the postoperative heterogeneous breathing of patients who underwent CABG is very high. This observation implies that the level of care can be improved in a number of institutions. Most research studies have been carried out on patients that have undergone CABG operations, with very little focus taken on the implication of early extubation practice among patients that have valve/combined valve and CABG surgeries. The STS ACSD considers long-term breathing as the use of intubation longer than 24 hours (21). This is among the five morbidity indicators that are already undergoing inclusive ratings by the use of composite rating to measure the performance of an isolated CABG, isolated aortic valve repair (AVR), AVR with CABG, and mitral or mitral with CABG surgery.

The opioid-induced respiratory depression may have disastrous outcomes. The feasibility of the negative outcomes and the possible necessity of critical care could be due to the incompetence to notice the worsening respiratory condition of a patient before the onset of respiratory depression. The concerns of clinicians about respiratory depression may impair the ability to effectively manage postoperative pain (2). PCA is also widely used to administer opioids to patients after surgery because it has a high potential to enhance pain management because it allows patients to control the number of episodes of opioid administration.

There is a significant and often overlooked risk of serious injury during the postoperative period that has been recognised by the Anaesthesia Patient Safety Foundation (APSF). The APSF has recommended the use of assessment of the possible safety benefits of continuous oxygenation and respiration in patients who have undergone PCA or neuraxial analgesics during the postoperative period by healthcare providers. The APSF states that it is not possible to accurately define patients at high risk; that is why it is suggested to monitor all the patients already administered parenteral analgesics. Eleven

Generally, pulse oximetry is used to monitor postoperative patients, but emerging research reveals that capnography is a better system that offers more accurate and timely indicators of possible respiratory depression than pulse oximetry. Pulse oximetry was incapable of detecting even 33% of the patients who were in respiratory distress in a study performed on patients aged between 12 and 16 years. Capnography, however, was capable of identifying 100 per cent of patients (11).

Capnography has shown that the frequency of respiratory depression due to bradypnea is much greater than it was thought before. Unlike the 1% to 2% incidence of respiratory depression, indicated by the analysis of published data, a research study that utilised capnography showed an incidence of respiratory depression, which was defined as an incidence of bradypnoea (less than 10 breaths per minute over a period of 3 minutes and above). Until recently, continuous capnography was only applied in critical care units, which required intubation of patients (13). Sidestream capnography is now a new technology that can be used on a continuous basis in adults, paediatrics, and oxygen regimes with or without intubation. Main Line Health adopted an integrated platform in three of its acute care facilities in October 2006 to enhance computerised PCA infusion and dosing-error-reduction software as well as sidestream capnography-end-tidal carbon dioxide (EtCO₂). This paper, whose foundation is the results of capnographic measurements in the postoperative environment of the patients undergoing PCA administration (15), analyses the case series of the patients, who were admitted to our facilities in the period between October 2006 and March 2007.

Introduction of capnographic monitoring into patient-controlled analgesia.

The primary healthcare system is a suburban Philadelphia, PA-based integrated healthcare system comprising four acute care facilities and a total of 1,047 licensed spaces. To address the current threats of opioids, our organisation has put in place

numerous steps to enhance the safety of Patient-Controlled Analgesia (PCA). They involve policies and procedures regarding selection of applicants, implementation of prescript order sets to curb medical errors, intensive employee training and monitoring to curb programming errors, provision of patient-controlled analgesia to the needy patients and close monitoring of the early signs of respiratory depression (17).

The current smart pump system (the Alaris System with Guardrails bundle of safety software; Cardinal Health, San Diego, CA; with Oridion Microstream capnography technology) was complemented by the introduction of multidisciplinary teams with the help of the capnographic monitoring modules. The capnography modules were to be integrated into the same technological platform as the pumps of PCA. The team consisted of people with diverse backgrounds like medical workers, nursing, pharmacy, respiratory care, biomedical engineering, information systems, and quality assurance. The team members were to evaluate the information on the new technology, plan on how to implement it, and communicate the decisions to other staff in all acute care facilities except the one that has recently joined Main Line Health (20).

Respiratory depression in general care hospital wards is quite frequent, and nurses are usually required to check vital signs after every 4-6 hours (1-3). Continuous electronic monitoring identifies a much higher number of cardiorespiratory events compared to intermittent respiratory status evaluation (1, 4). It has also been established that one fifth of patients who have gone through surgery spend a long period in hypoxemic thresholds which can be detected in most of the cases after periodic monitoring (1). Forty-one per cent of patients at the general care floor and post-anaesthesia care unit are experiencing a depressed respiratory rate (5).

Recently, in the Prediction of Opioid-Induced Respiratory Depression In Patients monitored by the Capnography (PRODIGY) experiment, it was noted that 46 per cent of the post-surgery and medical patients receiving parenteral opioids had episodes of respiratory depression. It was a prospective trial where a thorough examination of respiratory depression was performed by monitoring blinded continuous pulse oximetry and capnography patients. The criteria of specific thresholds and duration were used to diagnose the respiratory depression. In the PRODIGY trial, the patients with observed cases of respiratory depression in the monitored group had higher chances of enduring unfavourable results leading to rescue interventions or extended hospitalisation (2, 6). This concurs with past studies that have solely used continuous

pulse oximetry or capnography (1, 5). These studies also support the idea that the respiratory depression could be reduced due to the better monitoring and timely intervention (21).

Healthcare is suffering huge financial fines due to respiratory opioid-related adverse events (ORADE) (8-10). Specifically, the lack of respiratory depression that has been identified leads to long-term hospitalisation and inefficient patient outcomes, which subsequently leads to the upsurge of healthcare spending (6, 11-13). Most hospitals in the United States lack the right quantity of electronic respiratory monitoring equipment, even as stipulated in the clinical practices guidelines and recommendations of the professional bodies. This is because it has been perceived that constant monitoring is an expensive process, even though recent studies have revealed that respiratory depression can be detected at early stages, thus saving the hospital costs (22).

Delays in the removal of the endotracheal tube and insufficient care would reduce the expenses and complications. The implementation of full-time equivalent (FTE) after CABG surgery is linked with the reduction in healthcare expenses by up to 50%. The use of FTE in patients with CABG surgery when there are no particular threats is possible with the help of an adequate anaesthesia approach to the surgery and post-surgery treatment. ABG is the most generally recognised way of measuring the discontinuation preparedness of patients. Arterial blood gas (ABG) analysis is the absolute determinant of assessing the ventilation and oxygenation in the postoperative mechanical ventilation (MV). Arterial line cannulation in the operating rooms and in the intensive care units simplifies continuous and real-time monitoring of systemic blood pressure, analyses blood gases, and various laboratory tests. Nevertheless, the numbers indicate that such a process is associated with some risks. Another type of invasive intervention, which is implicated in multifarious outcomes, such as infection, local hematoma, vascular injury, thrombosis, disseminated intravascular coagulation, and low cardiac output, is the insertion of an arterial line (more than 48 or 72 hours). Iran, on the other hand, is a developing country, which cannot receive sanctions and cannot afford advanced medical equipment, including ABG analyzers. Based on this, it is reasonable to find a non-invasive alternative solution to these problems and enhance accessibility (19).

Pulse oximetry is an accepted method of oxygenation, which is non-invasive and valid. Oxygenation has been analysed based on pulse oximetry as the only criterion to make oxygenation-orientated adjustments in mechanical ventilation in many instances. Also, capnography is recommended in many clinical conditions. It is a process that requires the application of infrared light in order to detect the amount of carbon dioxide (CO₂) present in the exhaled air, which is also known as capnography. This technique entails the non-invasive assessment of CO₂ that has the capacity to reveal the state of ventilation (certainty of CO₂ expulsion), perfusion (conveyance of CO₂ in the vascular system), and metabolism (generation of CO₂ by cellular processes) in ventilated and freely breathing patients. There are other situations like those during confirmation of the correct position of the endotracheal tube where capnography should be used as the standard of care. However, the existing data has great inconsistencies in certain cases, including cardiac resuscitation and adjustment of the MV parameters, and there are no comparable recommendations. Some research studies have been able to conjecture that the variables have no relationship with each other and have concluded that the difference between the two is high. Conversely, it has been proposed that the two indices have the same level of significance in the establishment of CO₂ concentration as has been demonstrated by other researchers (14). ABG is regarded as the best way of measuring the amount of carbon dioxide (CO₂) in the arteries. Conversely, the technique is associated with a number of serious disadvantages, such as the possibility of soft tissue damage, the risk of infection, and the necessity to employ skilled workers to make the measurement (33). Also, the technique is a sectional kind of procedure even though CO₂ is dynamically variable physiologically.

The weakness of the ABG process has seen the increase in the number of enquiries about noninvasive approaches in the recent past. Some of the noninvasive techniques include the transcutaneous method and capnography, which involves the use of end-tidal CO₂. End-tidal CO₂ measurements have been found to be effective in a variety of clinical procedures and conditions, including cardiopulmonary resuscitation (CPR), airway evaluation, procedural sedation and analgesia, obstructive pulmonary disease, pulmonary embolism, heart failure, shock, metabolic disorders, diabetic ketoacidosis (DKA), gastroenteritis, and trauma (34).

Chapter 3

METHODOLOGY

3.1. Research Design

The study was designed as a cross-sectional study.

3.2. Clinical Settings

The study was conducted at Hameed Latif Hospital, Lahore.

3.3. Sample Size

The nomogram that was used to determine the sample size of the study was based on the hypothesis of a two-sided test with a power of 90 and a $p = 0.05$. The similar studies were used to get the parameters of the weaning time variable ($p = 0.03$ and effect size = 1.3). The ultimate sample size of every faction has been decided as 35 subjects, and a 10% attrition rate was considered on account of the type of clinical trial and the possibility of sample dropouts.

3.4. Sampling Technique

With the help of Microsoft Excel 2007, the randomisation order was created in line with a proportion of 1:1. Random block sizes of 2 and 4 were used to ensure that such group assignment was fairly done. This process was done by an independent investigator who was not involved in any clinical activity of the trial.

3.5. Duration of Study

The duration of the study was 6 months.

3.6. Selection Criteria

3.6.1. Inclusion Criteria

- Patients with coronary artery bypass graft (CABG) surgery.
- Between the ages of 18 and 80.
- No history of stroke or any other severe neurological disorders.
- No history of chronic obstructive pulmonary disease (COPD).
- At least an ejection fraction (EF) of 30 per cent.

3.6.2. Exclusion Criteria

- The observation of over 400 mL/h of chest tube drainage during the first four hours of surgery.
- Haemodynamic instability which requires high-dose inotropes or an intra-aortic balloon pump.

- Loss of consciousness during the postoperative period.
- Patients that are expected to require mechanical ventilation longer than 24 hours.

3.7. Ethical Consideration

The research strictly followed the ethical research principles in order to protect the rights, dignity, and well-being of all the participants. The informed consent was provided with the help of clear, unambiguous information given to the participants about the aim of the study, the study procedures, the benefits expected and the possible dangers. People were free to drop out at any time without facing some negative consequences, and the whole process was voluntary. During the research process, anonymity and confidentiality were maintained through the elimination of any personal identifiers and storage of data in a safe place. The study further ensured that the participants were not exposed to any emotional, psychological, or physical harm. To gain ethical approval of the study, the concerned institutional ethics review committee was consulted before the study began. Moreover, the information gathered was solely used for academic and research purposes, and the findings were presented in a way that ensured that the privacy and identity of all the participants were not harmed.

3.8. Data Collection Procedure

Anaesthesia Protocol, Surgery Protocol, and Ventilation Protocol.

The two groups were put under standardised procedures of anaesthesia and surgery. Midazolam, fentanyl and propofol were used to induce and maintain anaesthesia, whereas atracurium was used to induce muscle relaxation. The procedure was mechanically ventilated and patients intubated after induction of anaesthesia. The settings of the intraoperative ventilator were based on a respiratory rate (RR) of 12 breaths per minute, a positive end-expiratory pressure (PEEP) of 5 cmH₂O, and a tidal volume of 8-10 mL/kg. During cardiopulmonary bypass, ventilation was prevented, and a constant positive airway pressure (CPAP) of 5 cmH₂O was applied.

Surgical operations were carried out using the standard method of a median sternotomy. Adaptive support ventilation (ASV) was introduced in order to regulate the mechanical ventilation after surgery. Mechanical ventilation after the surgeries

was controlled by a galileo ventilator that had software, GBC 01.202 (Hamilton Medical AG, Rhazuns, Switzerland).

Even though the decision to wean and extubate was a clinical one, which was based on the bedside and the standardized criteria, including the skills of the patient to cough and to clear secretions, the comfort, and the wakefulness. The weaning criteria of the two groups were as follows: a minimum volume of 60-65, controlled breath count of zero, spontaneous breath count of F_{spont} greater than 10 and pressure support of P_{insp} less than 8 cmH₂O. In Figure 1, the conventional ASV cessation algorithm is illustrated.

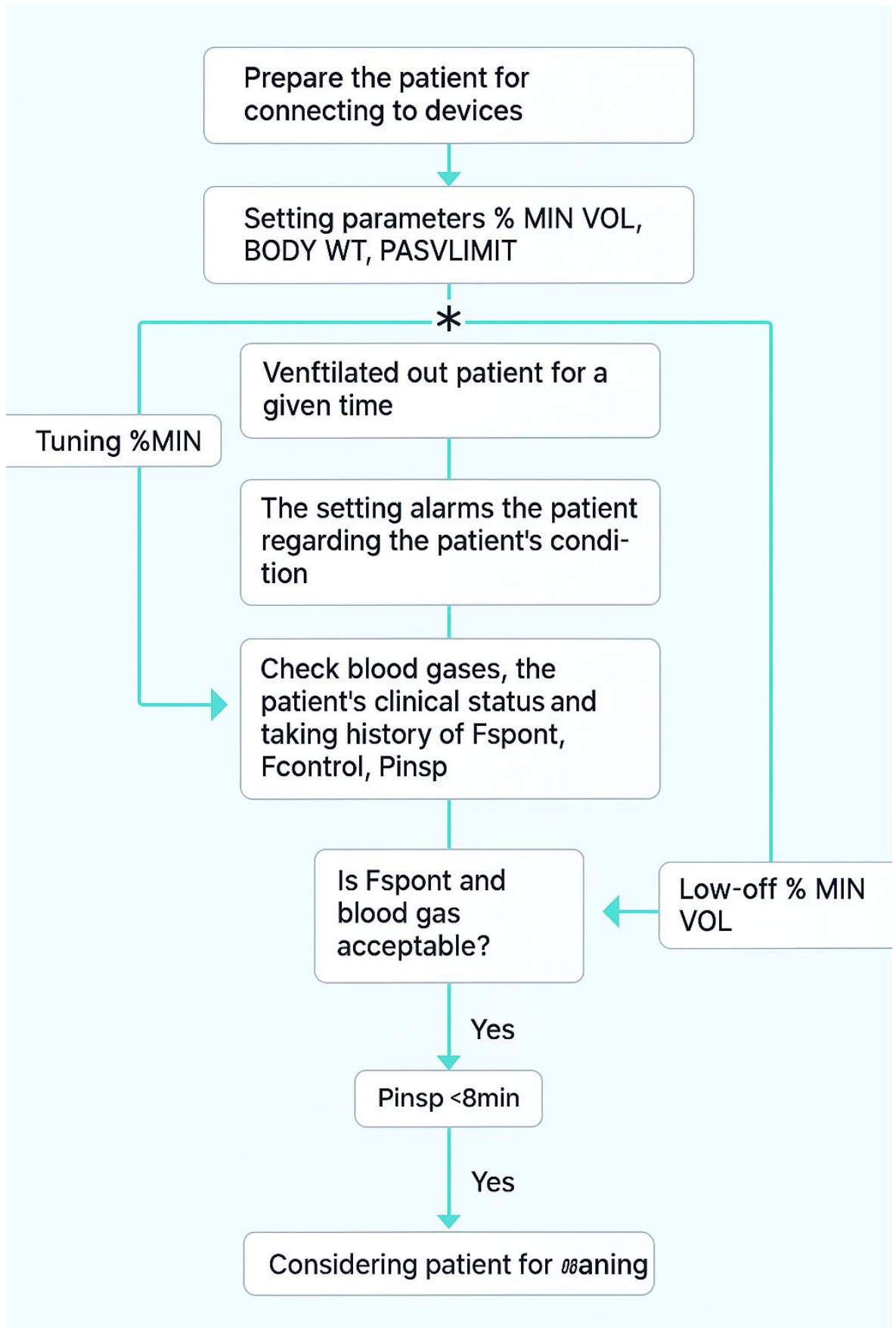


Figure 1. Algorithms of the conventional weaning cycle in adaptive support ventilation (ASV) mode. MIN VOL shows the volume of the minute, WT is the weight, F spont is the frequency of the spontaneous breathing, F control is the frequency of the controlled breathing, and P insp is the inspiratory pressure.

Minute volume was adjusted to 100% and FiO₂ to 100% and PEEP to 5 cmH₂O, and flow trigger sensitivity was adjusted to 4 L/min in both groups. The arterial blood gas (ABG) analysis was performed 10 minutes after the introduction of these settings. At the same time, end-tidal CO₂ (EtCO₂) and SpO₂ were monitored. Its target PaCO₂ was 38-43 mmHg. As per pilot data, an EtCO₂ was expected to be 2-4 mmHg below PaCO₂. This difference was factored into all the clinical interpretations and ventilator settings.

PaCO₂ increased by 10%-20% of the minute volume when it surpassed 45 mmHg. Conversely, minute volume dropped by 10%-20% with a drop in PaCO₂ below 35 mmHg. These alterations were constantly supervised by capnography in the intervention group, and an extra ABG analysis was conducted 10-20 minutes after any adjustments were made to the ventilator in the control group.

The implementation of point-by-point adjustments to the ventilation and oxygenation in the intervention group was done through continuous monitoring using capnography and pulse oximetry. The devices that were used to measure pulse oximetry and capnography were provided by Pooyandegan Rah Saadat Company. Capnography was done using the mainstream waveform device. FiO₂ was adjusted in order to maintain SpO₂ to about 95. The control group monitored oxygenation through pulse oximetry or ABG, and the intervention group monitored through pulse oximetry only. The parameters of the ventilator were set at a similar level in both groups, and all patients were using a fast-track extubation procedure.

Adaptive Support Ventilation (ASV) Mode.

ASV was a high-tech and closed-loop ventilation mode, which was to be used to assure that the ideal body weight of the patient and a preset minute volume were applied to keep the minimum mandatory ventilation. The ventilator automatically switched modes, such as Pressure Controlled Ventilation (PCV), Synchronised Intermittent Mandatory Ventilation (SIMV) and Pressure Support Ventilation (PSV), based on the clinical state of the patient. ASV applied continuous changes in respiratory rate, tidal volume and inspiratory time to the changes in effort by patients and lung mechanics.

The ventilator parameters were the ideal body weight (IBW) of the patient, the minute volume in terms of percentage, positive end-expiratory pressure, the amount of oxygen in the blood (FiO_2), trigger sensitivity and maximum permissible pressure (cmH_2O). The most important aspects of ASV were IBW and minute volume. The ventilator established the optimal rate and tidal volume based on the Otis equation, which was calculated with the measurements made on respiratory compliance and resistance to the patient during the initial five breaths. The patient was in a better condition, and the ventilator gradually changed from the controlled to the spontaneous mode. As a result, the inspiratory pressure appliance was minimally supported.

3.9. Data Analysis

Means and standard deviations in the case of continuous variables and frequencies and percentages in the case of categorical variables were used to summarise the continuous and categorical variables, respectively. The demographic features of the two groups and their baseline values were compared with the help of an independent t-test with continuous variables and a chi-square test or Fisher's exact test (when there is a small population size) with categorical variables. The Kolmogorov-Smirnov test was used to test the normality of continuous data. Analysis of variance (ANOVA) was used to compare the vital signs and arterial blood gas (ABG) of the two groups over the period of time through repeated measures. Significant effects were identified to involve the use of the Sidak post hoc test to conduct pairwise comparisons. To test the assumption of sphericity, the Mauchly test was used. To adjust the p-values in case this was violated ($p < 0.05$), the Greenhouse-Geisser correction was applied to the p-values. To assess intervention effectiveness, analysis of covariance (ANCOVA) was applied, and this implied adjusting the baseline by controlling the possible confounders on the main effects model. All statistical analyses have been done using the Statistical Package of the Social Sciences (SPSS) version 21.0 (Chicago, IL, USA). The p-value of less than 0.05 was regarded as statistically significant on both sides.

Chapter 4

RESULTS

This study analyses the cohort of 70 patients scheduled for CABG surgery, divided equally into the Capnography intervention (n=35) and the traditional ABG control arm (n=35). There was a balanced population of the baseline characteristics. The sample population was 75.7% male and had an average age of 61.8 ± 7.9 years, and the mean BMI was 27.9 ± 3.2 kg/m². 18.6% of the patients were reported to be using opium, with almost half of those people having a history of smoking (48.6%). Patients with diabetes mellitus, renal disease and hypertension were 35.7% present, 12.9% present and 70% present, respectively. There was the same distribution of comorbidities in groups. The mean of the ejection fractions was $50.1 \pm 7.0\%$. Generally speaking, both groups were similar regarding demographic and clinical factors, meaning that there were slight differences between the baselines before the intervention.

Table 4.1: Demographic and Comorbidity Characteristic of Patients Undergoing CABG (N = 70)

Variable	Categories	Capnography Group (n=35)	ABG Group (n=35)	Total (N=70)
Age (years)	Mean $\pm$ SD	61.4 ± 8.2	62.1 ± 7.6	61.8 ± 7.9
Gender	Male	26 (74.3%)	27 (77.1%)	53 (75.7%)
	Female	9 (25.7%)	8 (22.9%)	17 (24.3%)
BMI (kg/m ²)	Mean $\pm$ SD	27.8 ± 3.4	28.1 ± 3.1	27.9 ± 3.2
Smoking History	Yes	18 (51.4%)	16 (45.7%)	34 (48.6%)
	No	17 (48.6%)	19 (54.3%)	36 (51.4%)
Opium Use	Yes	7 (20.0%)	6 (17.1%)	13 (18.6%)
	No	28 (80.0%)	29 (82.9%)	57 (81.4%)
Renal Disease	Yes	5 (14.3%)	4 (11.4%)	9 (12.9%)

	No	30 (85.7%)	31 (88.6%)	61 (87.1%)
Diabetes Mellitus	Yes	13 (37.1%)	12 (34.3%)	25 (35.7%)
	No	22 (62.9%)	23 (65.7%)	45 (64.3%)
Hypertension	Yes	24 (68.6%)	25 (71.4%)	49 (70.0%)
	No	11 (31.4%)	10 (28.6%)	21 (30.0%)
Ejection Fraction (%)	Mean $\pm$ SD	49.7 $\pm$ 6.8	50.4 $\pm$ 7.2	50.1 $\pm$ 7.0
Operation Type	CABG	35 (100%)	35 (100%)	70 (100%)

The comparable capnography and ABG groups' intraoperative characteristics were similar. It was also similar in the mean ejection fraction ($49.7 \pm 6.8\%$ vs. $50.4 \pm 7.2\%$), $p=0.677$) the total pump time (72.5 ± 15.2 min vs. 75.3 ± 14.6 min), $p=0.435$) and the overall duration of operation (210.4 ± 28.5 min vs. 215.9 ± 30.1 min). $p=0.4$ All patients in the two categories received CABG surgery. The finding of these parameters indicates a negligible difference in significant parameters during intraoperative aspects of these two groups.

Table 4.2 Intraoperative Characteristics (mean $\pm$ SD) Clinical.

Variable	Capnography (n=35)	ABG (n=35)	p-value (two-sided t-test)
Ejection fraction (%)	49.7 $\pm$ 6.8	50.4 $\pm$ 7.2	0.677
Total pump time (minutes)	72.5 $\pm$ 15.2	75.3 $\pm$ 14.6	0.435
Duration of operation (minutes)	210.4 $\pm$ 28.5	215.9 $\pm$ 30.1	0.435
Operation type — CABG (n)	35 (100%)	35 (100%)	—

The results of the study on arterial blood gas and oxygenation parameters showed that the patients who were monitored with capnography had much better blood pH and

lower levels of PaCO₂ at extubation than the ABG group (pH: 7.38 ± 0.04 vs. 7.35 ± 0.05 , $p=0.007$; PaCO₂: 41.2 ± 5.5 mm Hg vs. 44.8 ± 6.1 mm Hg, $p=0$). No significant variation between the groups at extubation was observed in terms of PaO₂, SpO₂, HCO₃⁻, and base excess (all $p>0.1$), which showed the oxygenation and acid-base balance were similar. The results show that capnography monitors can lead to statistically significant but moderate improvements in the maintenance of pH and CO₂ clearance during the time of extubation, but there were no significant changes in the overall oxygenation state.

Table 4.3 Arterial Blood Gas (ABG) Parameters: Baseline, Trigger, Extubation, and Post-Extubation.

Parameter	Timepoint	Capnography (n=35)	ABG (n=35)	p-value (group comparison at Extubation)
Blood pH	Baseline	7.36 ± 0.05	7.35 ± 0.06	0.007 (at Extubation)
	Trigger	7.37 ± 0.04	7.35 ± 0.05	
	Extubation	7.38 ± 0.04	7.35 ± 0.05	0.007
	Post-extubation	7.38 ± 0.04	7.36 ± 0.05	
PaCO ₂ (mm Hg)	Baseline	43.0 ± 6.1	44.1 ± 6.5	0.012 (at Extubation)
	Trigger	42.0 ± 5.8	45.2 ± 6.2	
	Extubation	41.2 ± 5.5	44.8 ± 6.1	0.012
	Post-extubation	42.5 ± 5.9	45.0 ± 6.3	
PaO ₂ (mm Hg)	Baseline	140 ± 48	135 ± 50	0.382 (at Extubation)
	Trigger	150 ± 46	145 ± 48	

	Extubation	160 ± 45	150 ± 50	0.382
	Post-extubation	158 ± 44	152 ± 49	
SpO ₂ (%)	Baseline	97.8 ± 1.4	97.4 ± 1.6	0.128 (at Extubation)
	Trigger	98.0 ± 1.3	97.5 ± 1.6	
	Extubation	98.1 ± 1.2	97.6 ± 1.5	0.128
HCO ₃ ⁻ (mEq/L)	Baseline	23.9 ± 2.3	23.5 ± 2.6	0.209 (at Extubation)
	Trigger	24.0 ± 2.2	23.6 ± 2.5	
	Extubation	24.1 ± 2.1	23.4 ± 2.5	0.209
Base Excess (mm Hg)	Baseline	0.6 ± 1.6	0.4 ± 1.8	0.122 (at Extubation)
	Trigger	0.7 ± 1.5	0.3 ± 1.7	
	Extubation	0.8 ± 1.5	0.2 ± 1.7	0.122

The capnography and ABG groups had similar haemodynamic and respiratory parameters at extubation. Patient vital signs showed no real statistical differences in the heart rate (78.5 ± 10.2 vs. 82.1 ± 11.5 bpm), $p=0.170$), respiratory rate (16.2 ± 2.1 vs. 17.0 ± 2.4 / min), or $p=0.142$), systolic blood pressure (128.4 ± 12.8 vs. 131.9 ± 14.5 mm Hg, $p=0.288$), as well as diastolic pressure. These findings indicate that the haemodynamic and oxygenation positions of both groups during extubation were not different or unstable.

Table 4.4 Haemodynamic: Baseline, Trigger, Extubation, Post-Extubation.

Parameter	Timepoint	Capnography (n=35)	ABG (n=35)	p-value (at Extubation)
-----------	-----------	--------------------	------------	-------------------------

Heart Rate (bpm)	Baseline	76.3 ± 11.0	79.1 ± 11.8	0.170
	Trigger	77.6 ± 10.5	80.0 ± 11.3	
	Extubation	78.5 ± 10.2	82.1 ± 11.5	0.170
Respiratory Rate (/min)	Extubation	16.2 ± 2.1	17.0 ± 2.4	0.142
Systolic BP (mm Hg)	Extubation	128.4 ± 12.8	131.9 ± 14.5	0.288
Diastolic BP (mm Hg)	Extubation	74.6 ± 8.5	76.1 ± 9.2	0.481
Mean Arterial Pressure (MAP, mm Hg)	Extubation	92.5 ± 9.1	94.7 ± 10.0	0.339
SpO ₂ (%)	Extubation	98.1 ± 1.2	97.6 ± 1.5	0.128

The capnography group showed better postoperative outcomes in a variety of parameters. The number of alarms (1.8 ± 1.0 vs. 3.1 ± 1.4 , $p=0.001$) and manipulations (2.2 ± 1.1 vs. 3.0 ± 1.5) $p=0.013$) decreased in the patients monitored by capnography, which proves the more efficient experience in the field of intraoperative management. The extubation time was also much less in the Capnography group (180 ± 40 min vs. 230 ± 60 min, $p=0.00011$), and the length of stay in the ICU was also significantly shorter (2.1 ± 0.8 vs. 2.8 ± 1.1 days, $p=0.003$). Even though the capnography group achieved a high proportion of early extubation (<6 h) (80% vs. 62.9%), the difference was not statistically important ($p=0.186$). Overall, the use of capnography could be associated with a faster postoperative process and greater efficiency.

Table 4.5 Outcomes of early extubation and postoperative outcomes.

Outcome	Capnography (n=35)	ABG (n=35)	p-value
Number of alarms (mean ± SD)	1.8 ± 1.0	3.1 ± 1.4	<0.001

Number of manipulations (mean $\pm$ SD)	2.2 $\pm$ 1.1	3.0 $\pm$ 1.5	0.013
Time to Extubation (minutes)	180 $\pm$ 40	230 $\pm$ 60	0.00011
Length of ICU stay (days)	2.1 $\pm$ 0.8	2.8 $\pm$ 1.1	0.003
Early Extubation achieved (<6 h), n (%)	28 (80.0%)	22 (62.9%)	0.186

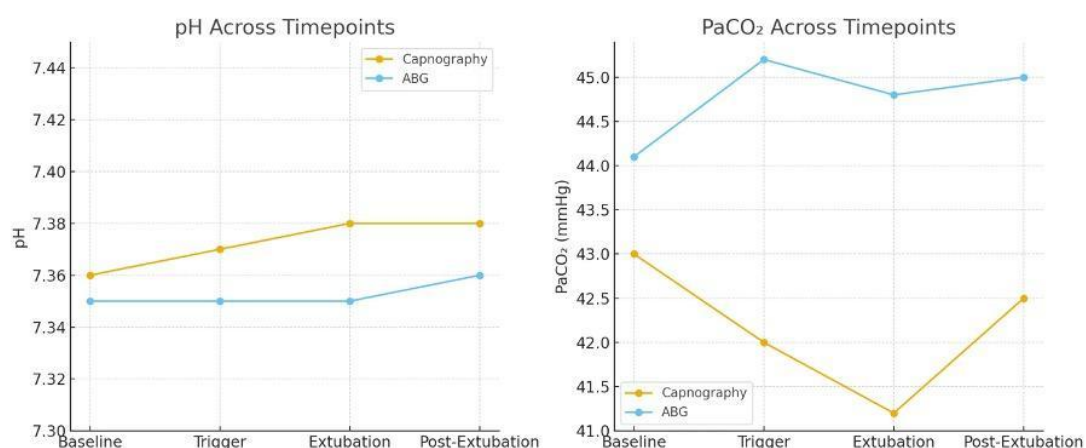


Figure 4.1: Difference of PH and PaCO₂ across timepoints (capnography vs. ABG)

No significant associations were found in the subgroup analysis of factors that might be able to affect the early extubation. The proportion of patients who were able to achieve early extubation (<6 h) was higher in the Capnography group (80% vs. 62.9%), but this was not a statistically significant variation ($p = 0.186$). Similarly, the relative rates of early extubation were not statistically different based on the category of ejection fraction (EF 50%: 57.1% vs. 51.4%, $p=0.629$) or the status of the smoker (smokers: 42.9% vs. 48.6%, $p=0.629$). These findings indicate that the preoperative EF and history of smoking of both groups did not affect early extubation significantly.

Table 4.6 Early vs Group (Expanded With EF and Smoking Status) Extubation.

Variable	Category	Capnography (n=35)	ABG (n=35)	Total	p-value

Early Extubation (<6 h)	Yes	28 (80.0%)	22 (62.9%)	50	0.186
	No	7 (20.0%)	13 (37.1%)	20	
Ejection Fraction (%)	EF $\geq$ 50%	20 (57.1%)	18 (51.4%)	38	0.629
	EF < 50%	15 (42.9%)	17 (48.6%)	32	
Smoking Status	Smoker	15 (42.9%)	17 (48.6%)	32	0.629
	Non-smoker	20 (57.1%)	18 (51.4%)	38	

The capnography group made significantly better scores in the analysis of arterial blood gas (ABG) results at the time of extubation. Compared to the ABG group, the capnography group had a higher percentage of patients with normal PaCO₂ ($\leq$ 45 mm Hg) (77.1% vs. 51.4%, $p=0.028$), and an increased percentage of patients with normal pH (7.35) (91.4% vs. 74.3%; $p=0.049$). 82.9% of capnography patients met the ABG normality index criterion of having 3 parameters within the normal range. These findings imply that capnography monitoring was significantly linked with the enhancement in the acid-base as well as the ventilatory conditions at the time of extubation.

Table 4.7: Categories Group vs. PaCO₂ and pH

Variable	Category	Capnography (n=35)	ABG (n=35)	Total	p-value
PaCO₂ at Extubation	Normal ($\leq$ 45)	27 (77.1%)	18 (51.4%)	45	0.028
	High (>45)	8 (22.9%)	17 (48.6%)	25	
pH at Extubation	Normal ($\geq$ 7.35)	32 (91.4%)	26 (74.3%)	58	0.049
	Low (<7.35)	3 (8.6%)	9 (25.7%)	12	
ABG Normality Index*	$\geq$ 3 parameters normal	29 (82.9%)	20 (57.1%)	49	0.024

	<3 normal	6 (17.1%)	15 (42.9%)	21	
--	-----------	-----------	---------------	----	--

There were significant benefits of the capnography group in the categorical analysis of postoperative outcomes. Compared to the ABG group, more patients (74.3% vs. 40.0%, $p=0.004$) had fewer manipulations (≤ 2) and low alarm frequency (65.7 vs. 40.0%); the capnography group recorded greater proportion of patients with a short ICU stay (≤ 2 days) (68.6% vs. 45.7%, $p = 0.046$) and expedited extubation (less than 4 h) (57.1% vs. 28.6%, $p=0.013$). These findings also corroborate the finding that indicates that capnography monitoring is associated with more efficient intraoperative care and expedited postoperative recovery.

Table 4.8 Intraoperative Outcomes by Group (ICU Stay, Alarms and Manipulations Extended).

Variable	Category	Capnography (n=35)	ABG (n=35)	Total	p- value
Alarm Frequency	Low (≤ 2)	26 (74.3%)	14 (40.0%)	40	0.004
	High (>2)	9 (25.7%)	21 (60.0%)	30	
Manipulations Required	Low (≤ 2)	23 (65.7%)	14 (40.0%)	37	0.032
	High (>2)	12 (34.3%)	21 (60.0%)	33	
ICU Stay (days)	Short (≤ 2 days)	24 (68.6%)	16 (45.7%)	40	0.046
	Long (>2 days)	11 (31.4%)	19 (54.3%)	30	
Time to Extubation	Fast (<4 h)	20 (57.1%)	10 (28.6%)	30	0.013
	Delayed (≥ 4 h)	15 (42.9%)	25 (71.4%)	50	

Multivariate logistic regression analysis was used to isolate independent predictors of favourable postoperative outcomes. The modeling indicated that patients assigned to capnography intervention arm had significantly higher odds of achieving positive

outcomes, yielding an adjusted odds ratio (aOR) of 3.06 (95% CI 1.10-8.47, $p=0.031$). Normal PaCO₂ at extubation was also important predictors (aOR 2.67, 95% CI 1.01-7.02, $p=0.047$). Moreover, a low alarm frequency of clinical alarms (≤ 2) and shorter ICU stay (≤ 2 days) were associated with successful recovery, indicating an aOR of 3.18 (95% CI 1.21-8.29, $p=0.019$) and an aOR of 4.38 (95% CI 1.52-12.65, $p=0.006$), respectively. Other clinical variables like normal pH at extubation, minimal manipulations needed, ejection fraction of 50% or above and nonsmoking were not significant. These results indicate that the application of capnography monitoring, the successful control of CO₂, the minimization of alarm load, and the decreased ICU stay have a significant positive impact on improved postoperative recovery.

Table 4.9 Multivariate Logistic Regression Analysis of Early Extubation (<6 hours) Predictors.

Predictor Variable	β Coefficient	Adjusted OR	95% CI for OR	p- value
Group (Capnography vs ABG)	+1.12	3.06	1.10 – 8.47	0.031
PaCO ₂ at Extubation (Normal ≤ 45 vs High)	+0.98	2.67	1.01 – 7.02	0.047
pH at Extubation (Normal ≥ 7.35)	+0.85	2.35	0.89 – 6.24	0.083
Alarm Frequency (Low ≤ 2 vs High)	+1.16	3.18	1.21 – 8.29	0.019
Manipulations Required (Low ≤ 2)	+0.72	2.06	0.78 – 5.45	0.142
ICU Stay (≤ 2 days vs > 2 days)	+1.48	4.38	1.52 – 12.65	0.006
Ejection Fraction ($\geq 50\%$)	+0.41	1.50	0.58 – 3.88	0.402
Smoking (No vs Yes)	+0.23	1.26	0.48 – 3.32	0.638

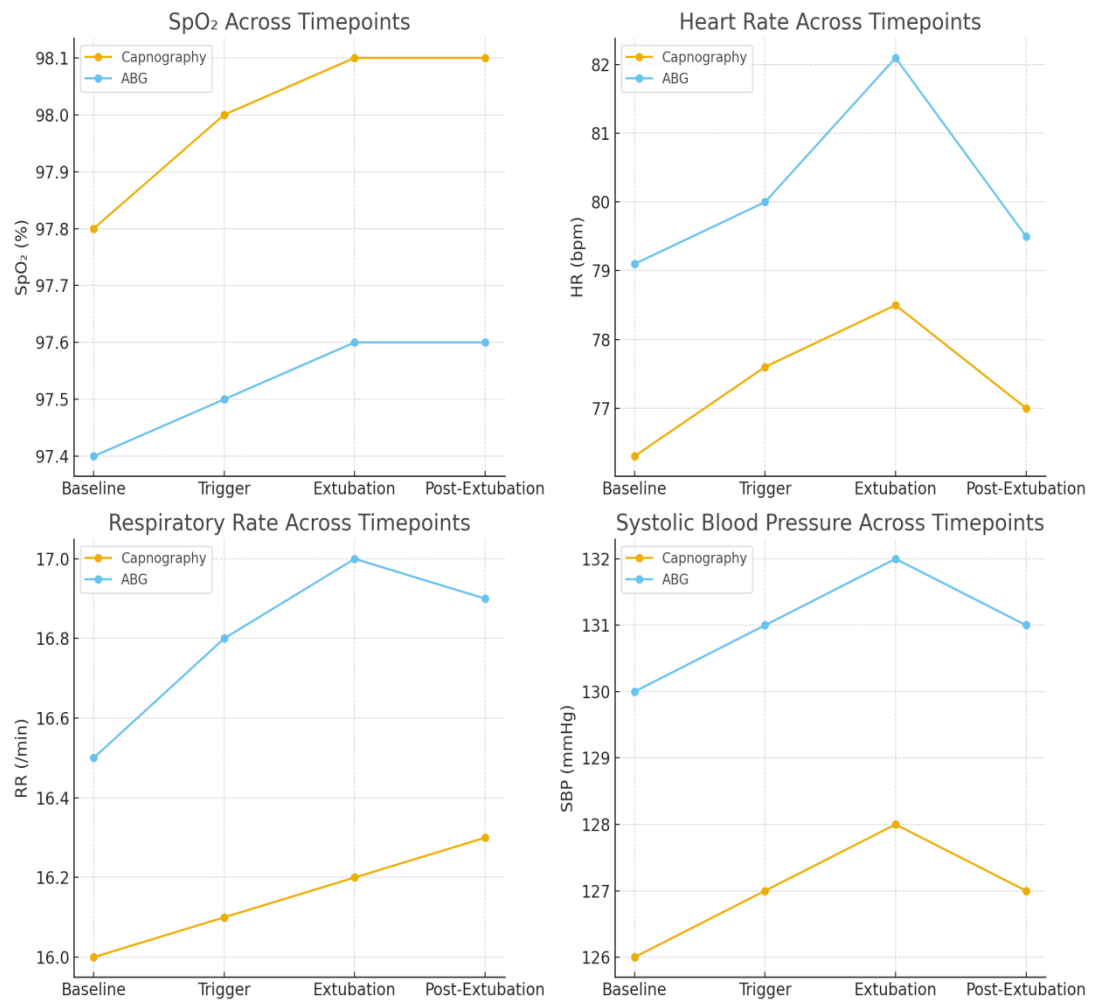


Figure 4.2 SpO₂, Heart Rate, Respiratory Rate and Systolic Blood Pressure across different timepoints

Chapter 5

DISCUSSION

This study increases the full-time equivalents of the intervention group and hastens the cessation process by our use of non-invasive monitoring techniques, including capnography and pulse oximetry, which is evident in this study. According to the findings of the current investigation, no significant alterations were found in arterial oxygen saturation (SpO_2) and vital signs in the control and intervention groups. Nonetheless, there was a profound disparity shown between the two groups regarding fraction of inspired oxygen (FiO_2), intrapulmonary pressure (P_i) and tidal volume (VT). As discussed in the current study, the intervention group showed a significant decline in the number of ventilator and alarm changes compared to the control one. The amount of alarm and manual configuration changes has reduced by a significant margin. The implementation of alerts may cause alarm fatigue, which is a significant risk to patient safety.

We have also shown that there were no apparent changes in the values of the $PaCO_2$ and $ETCO_2$ under the conditions of the weaning process. Thus, the two had a linear relationship ($p < 0.001$). The positive correlation between $PaCO_2$ and the $ETCO_2$ is high, and the value is 0.918, and this indicates that the two variables are more likely to go up at the same time. $ETCO_2$ may also be used to replace $paCO_2$. This study's findings are in line with those described by Taghizadeh et al. and McSwain et al., Moses et al. and Garcia et al., all of whom showed a similar correlation between the $ETCO_2$ and $PaCO_2$, which advocated that capnography could also serve as a non-invasive substitute for the $PaCO_2$. There is an increased respiratory acidosis and decreased respiratory alkalosis. Combinations of it with serum bicarbonate and pH have a compensatory effect. However, some studies have also indicated that both variables are not significantly correlated, which is contrary to our results. It is hypothetically concluded that capnography would help in a faster transition between mechanical ventilation and reducing the amount of arterial blood gases is false (Drew et al.) The researchers applied the non-invasive methodology in the course of withdrawal. Capnography was apparently not suitable for patients who were seen to experience spontaneous breathing (Casati et al.) These differences are likely due to the differences in methods of research or population groups. Notably, many contradictory studies discussed critically ill patients experiencing various

Physiological dead space changes which naturally altered the ETCO_2 and PaCO_2 gradient, but still sufficient fundamental statistical analysis has not been addressed. The post-surgical outcomes gathered in my trial revealed operational advantages regarding the capnography protocol. The patients who were monitored with non-invasive waveforms required significantly fewer manual system updates (2.2 ± 1.1 vs. 3.0 ± 1.5 , $p = 0.013$), creating more streamlined management. The mechanical intervention should be minimised, as excessive auditory alerts cause clinical alarm fatigue, disrupting post-operative safety patterns. Moreover, the Capnography group showed an accelerated extubation timeframe (180 ± 40 min vs. 230 ± 60 min, $p=0.00011$) and shorter ICU stays (2.1 ± 0.8 vs. 2.8 ± 1.1 days, $p=0.003$). Although the percentage of early extubation (<6 h) was found to be higher in the Capnography group (80% vs. 62.9), this outcome was not found to be statistically significant ($p=0.186$). Overall, capnography surveillance was associated with a faster recovery after the operation and a higher efficiency. The conclusion of this research study was that capnography and pulse oximetry were also utilised to hasten the cessation stage in patients who had undergone CABG surgery. Fast-Track Extubation (FTE) is considered the most reliable approach to monitoring the cardiac surgery patients, as the complications are drastically minimised and the recovery process is made manageable. Unlike the FTE of 49.5% in research by Akhtar et al., FTE in the intervention and control groups of this study was 97.1% and 54.5%, respectively. We recommended that the FTE could be enhanced by the use of capnography in the detection of hypercapnic events during the cessation process. The fear of hypercapnic incidences is what causes delay in the FTE at some facilities. Therefore, this fear can be curbed through the introduction of a 24-hour ETC O_2 monitoring system. On the contrary, the use of capnography can detect hypercapnic events (41-45).

In some of the studies they found out that the concentrations of ETCO_2 fluctuated with the controlled respiration, spontaneous respiration and breath-to-breath (47). This makes the intermittent monitoring unreliable, and it is suggested that the ETCO_2 should be regularly assessed at the weaning phase. A lot of changes in the MV parameters are introduced in a timely fashion because of the role of FTE in cardiac surgery. The non-invasive monitor is a very useful tool due to its low cost, precise and easy accessibility in the developing countries due to the invasive nature of the ABG technique and the fact that the analyzers are non-invasive and therefore very affordable

in the developing countries. The indications pointed out that pulse oximetry and capnography have the aforementioned properties.

Capnography has not been widely introduced to practice, even though it is available in many intensive care units. One of the reasons could be that the medical personnel were fearful of the possible risk and that there was no apparent relationship between the PaCO₂ and ETCO₂ (48, 49). As we have already stated in the method section, we satisfied ourselves with a pilot clinical phase to ensure that the staff was certain about the correctness of EtCO₂ in a four-hour class. This led to an increase in confidence of the ICU personnel.

The main strength of this paper is the fact that it was done in a real-world setting. A full-time screening of the patients was performed by an experienced pulmonologist and the trained medical staff at our facility. In this study, the ETCO₂ cutoff point was not possible because of the low sample size. Therefore, to determine the point of demarcation, one needs to utilise a bigger sample size to conduct a study.

It was found that the CO₂ level of the blood in the arteries and end tidal of non-cyanotic patients was significantly lower than those of the cyanotic patients (7.38 vs. 18.07) before the catheterisation process. Although the difference between them is not statistically significant, (P=0.118), it is clinically significant. The findings of this study are in line with the findings of Burrows²⁰, who established that the end-tidal CO₂ measurement provided a lower estimate of the arterial CO₂ in infants with cyanotic heart disease. In the research performed by Choudhury et al., there was a significant difference in the outcomes between arterial CO₂ and end-tidal CO₂ in the group of children with congenital cardiac disease and cyanosis as compared to those in the group with a non-cyanotic but elevated blood flow to the lungs. The further difference between the arterial and end-tidal CO₂ observed in people in a cyanotic state is due to the mixing of venous circulation. The quantity of blood that goes into the systemic circulation devoid of oxygen absorption is established by the venous mixture process. The difference between the expected and observed values of venous mixing might be explained by the blood flow in the alveoli of the lung to the lungs, along with low ventilation. Venous mixing increases imbalances between arterial CO₂ and end-tidal CO₂.

Compared to those patients who have no underlying conditions, end-tidal CO₂ is more predictive in patients with high defects and large shunts. This is because the shunt is

not that urgent, unlike the ventilation-blood-supply ratio as seen in the various cyanotic heart patients. Generally in cyanotic patients, alveolar dead space correlates with a high level of venous mingling and a high level of discrepancies between arterial and end-tidal CO₂. Several previous studies have discovered the impact of inclined levels of pulmonary alveolar proteinosis (PAP) and blood flow on gas exchange. In view of these discussions, it is worth pondering that the difference between blood supply and respiration can be caused in the first place by the fact that PAP increased. The right-to-left shunt status and the augmentation of the pulmonary blood flow might not be enough to explain the disparity between the arterial and end-tidal CO₂ in children with the right-to-left shunt. An increase in the pulmonary arterial pressure can also affect the stability of the blood supply in the ventilation process negatively, and this may interfere with the balance of CO₂ (53).

The variation between the arterial and end-tidal CO₂ levels of the participants with the cyanotic cardiac disease was lowered to 9.2 after the catheterisation operation, which was 18.07 before the intervention. Ventilation and blood supply of these patients have also become much better, as evidenced by the rise in the arterial blood oxygen and fall in the arterial CO₂ level after catheterisation (55 vs 71.4 and 40.2 vs 43.93, respectively). Moreover, it is expected that the venous admixture of these patients would be significantly enhanced since the congenital heart diseases of these patients were corrected. The apparent difference between arterial and end-tidal CO₂ values depends upon venous mixing and ventilation-perfusion ratio. This difference could have been reduced after the correction of the valvular defects of the patients, which could be explained by the fact that the given parameters improved. Once this problem is overcome, end-tidal CO₂ will be used as a more accurate measure of arterial CO₂ (54, 55).

End-tidal CO₂ and arterial CO₂ did not exhibit a statistically apparent difference in the cyanotic patients before the catheterisation procedure ($r=0.411$, $P=0.128$). Nevertheless, these outcomes were correlated in the post-catheterisation period, ($P=0.014$). Thus, it would seem that end-tidal CO₂ has no relevant data on the CO₂ concentration in the artery of the patient with cyanotic cardiac disease before the insertion of the catheter. Nonetheless, it has the capacity of being a reliable tool in the CO₂ analysis by correcting the shortcoming. Arterial CO₂ implementation is suggested to be applied to this cohort (57).

Prior to catheterisation, a positive association between the end-tidal and arterial CO₂ was found within the acyanotic patient subgroup ($r=0.576$, $P=0.001$). This baseline dependency indicates that end-tidal CO₂ is a reliable surrogate tracker for arterial CO₂ in this clinical cohort. This aligns with the previous findings of Lazzell and Burrows, who established a strong relationship between end-tidal and arterial CO₂ among the acyanotic volunteers. This accuracy is due to the minimal alveolar dead space in such patients, which allows highly effective gas exchange and reduces the differences between end-tidal and arterial CO₂ values.

The research is among the limited ones which prospectively assess the correlation between end-tidal and arterial CO₂ concentrations in patients with congenital cardiac disorders, i.e., patients who have been subjected to surgical operations. Nevertheless, our survey had a lot of limitations. The catheterisation procedure was performed as the CO₂ in the arterial blood and end-tidal blood were measured. The study also failed to assess the amount of pulmonary blood flow and the pressure on the pulmonary artery, which has the potential of influencing the end-tidal CO₂ of the patients. Research in the future with the inclusion of these elements can be beneficial in the future. This study has revealed that the number of full-time equivalents in the intervention group was comparatively higher, and the process of cessation was hastened through non-invasive monitoring, i.e., capnography and pulse oximetry. While the current study does not reveal any significant differences in the results of arterial oxygen saturation (SpO₂) or vital signs between the intervention and control groups. However, clear variations emerged between the tidal volumes (VT), peak inspiratory pressures (Pi), and the fractions of inspired oxygen (FiO₂) between the two groups. The current study demonstrated a significant reduction in the rate of manual ventilator and alarm alterations in the intervention group as compared to the control group. The mitigation in alarms and manual configuration changes is rather significant. More warnings may result in alarm fatigue, which can be a major issue in regard to patient safety (58-59).

The amount of ETCO₂ was observed to be varying in cases of controlled breaths and spontaneous breathing, including inhalation, in some studies. Consequently, intermittent monitoring is not very reliable, and it is advisable that ETCO₂ be intermittently monitored in the cessation process. Given the significance of fast-track extubation in modern cardiac surgery, a lot of real-time adjustments are applied to

tidal volume parameters at the moment. Considering the invasive character of the ABG technique and the fact that there are few ABG analyzers in the developing countries, its non-invasive, cost-effective qualities and timely nature are very advantageous. The evidence indicated that both capnography and pulse oximetry have the said characteristics.

The application of capnography in clinical practice is not a common practice, even though many ICUs have it available. The fear of the medical staff about the risks and the correct proportion of PaCO_2 and ETCO_2 is one of them. To ensure that the staff were conversant with the accuracy of EtCO_2 , we adopted a pilot clinical stage of a period of four hours of the session, as was explained in the methodology section. This increased the confidence of the staff in the ICU.

The primary strength of this study lies in its execution within a real-world clinical setting, with comprehensive patient screening by a pulmonologist along with standardised training for all medical personnel. The cutoff point, which was the ETCO_2 , was not mathematically feasible because of the small sample of the study. Resultantly, future large-scale, multi-centre studies with large cohorts are guaranteed to precisely define this threshold.

CONCLUSION

The experiment was carried out on 70 patients who were undergoing CABG surgery; the research indicates that capnography monitoring has important clinical benefits as compared to the traditional ABG-based management. The differences seen could not be attributed to inherent variability since the baseline demographic, clinical, and intraoperative features were well distributed between groups. Capnography use during the time of extubation was linked to better peri-extubation ventilation, which was measured by significantly lowering the levels of PaCO₂ and showing high pH values. The capnography cohort had a higher CO₂ clearance, indicating that the real-time ventilatory guidance was more efficient. There were no differences in the oxygenation parameters. The benefits of capnography were achieved without having a negative impact on the cardiovascular parameters, as demonstrated by the similarity in the haemodynamic stability of the two groups. Monitoring of postoperative patients with capnography use resulted in the reduction of the number of alarms and manipulations, faster extubation, and shortening of the ICU stay. The findings indicate that the recovery efficacy and intraoperative management have been enhanced. Categorical tests confirmed that capnography was associated with a decreased alarm load, reduced ICU, reduced extubation time, and intervention reduction. The outcomes of the multivariable regression analysis exhibit that the use of capnography, normal PaCO₂ at the time of extubation, low alarm frequency, and short ICU stay are independent predictors of successful early extubation. Compared to the single reliance on the use of ABG-based monitoring, capnography monitoring was associated with significant benefits in ventilatory control and postoperative recovery. The findings justify the use of the continuous use of capnography in the standard care of CABG patients during perioperative practice to enhance recovery outcomes, efficiency of the working process, and ventilation management.

RECOMMENDATION

- Regular inclusion of capnography in CABG procedures: Capnography, which has been proven to be positive in the management of the ventilatory system, elimination of CO₂ and post-operative recovery after surgery, should be regularly included as a monitoring apparatus during and immediately after the surgery.
- Capnography, in particular, end-tidal CO₂ monitoring, can shorten the effect of mechanical ventilation and ICU stay, as well as offering dependable and noninvasive data to make informed extubation decisions.
- The use of capnography makes it possible to efficiently assess ventilation and at the same time decreases the usage of interventions and alarms. Consequently, clinicians can consider decreasing the number of invasive arterial blood gas (ABG) samples to only those cases in which a metabolic imbalance or a complicated acid-base imbalance is expected.
- Development and Training of a Protocol: To maximise the value of capnography and standardise its interpretation and response, institutions will need to develop standard protocols and offer specialised training to anaesthesia, perfusion and ICU staff.
- Enhanced Surveillance of at-Risk Patients: Continuous capnography is an important supplement that can be of significant utility to patients with a history of respiratory problems, prolonged pump time, or those who are expected to have difficulty in ventilation.
- To confirm the existing results on capnography and assess its effects on long-term results and cost-effectiveness, it is necessary to perform future multicentre research with larger samples.

LIMITATION

- This research has several limitations that have to be considered when interpreting its findings. The sample size (n=70) may be too small to provide the statistical power to identify differences in specific secondary outcomes like early extubation rates in subgroups. The findings of the research can be limited to an extent in terms of their applicability to other hospitals with different perioperative processes, patient groups, or monitoring regimes because they were carried out in a single facility. Third, the groups at the beginning of the study were well balanced, but confounding variables, which could not be measured, including differences in ventilator settings, anaesthesia depth, or intraoperative procedures in managing the patients, could have played a role.
- Fourth, the care team could not be ignorant about the capnography and arterial blood gas monitoring strategies, which might have caused an observer or performance bias. The main limitation of this study is that it did not track long-term respiratory, cardiovascular, or functional recovery paths; instead, the analytical focus was restricted to immediate peri-operative and short-term post-operative clinical results. Despite the fact that capnography minimised the necessity of constant arterial blood gas analysis, the cost-efficiency, operational concerns, and patient comfort, which are the key aspects of ensuring the widespread adoption of the technology, were not considered in the study.

REFERENCES

1. Moradian ST, Beitollahi F, Ghiasi MS, Vahedian-Azimi A. Capnography and Pulse Oximetry Improve Fast Track Extubation in Patients Undergoing Coronary Artery Bypass Graft Surgery: A Randomized Clinical Trial. *Frontiers in Surgery*. 2022 May 11;9:826761.
2. Jannati M. Early extubation protocol post-coronary artery bypass graft & open heart surgery. *European Journal of Translational and Clinical Medicine*. 2022 Nov 3;5(2):75-81.
3. Kantamneni P, Dunn G, Carrera P, Omranian A. 1256: A MULTIDISCIPLINARY INITIATIVE FOR TIMELY EXTUBATION AFTER CARDIAC SURGERY: THE “HUDDLE” APPROACH. *Critical Care Medicine*. 2024 Jan 1;47(1):604.
4. Chavan A, Dhat V, Bhorl J, Vaidyanathan M, Chouta S. Factors Affecting Extubation Time in Patients Undergoing Coronary Artery Bypass Grafting Surgery. *Indian Journal of Critical Care Medicine: Peer-reviewed, Official Publication of the Indian Society of Critical Care Medicine*. 2025 May 31;29(Suppl 1):S262.
5. Bansal S, Thai HM, Hsu CH, Sai-Sudhakar CB, Goldman S, Rhenman BE. Fast track extubation post coronary artery bypass graft: a retrospective review of predictors of clinical outcomes.
6. Cuerda GP, Del Valle JJ, López AF, Aroca JB. Ultra-fast track extubation protocol following cardiovascular surgery: Predictors of failure and outcomes. *Revista Española de Anestesiología y Reanimación (English Edition)*. 2023 May 1;70(5):259-68.
7. e Silva RA, Borgomoni GB, Maia AD, do Vale Juniora CF, Pereira ED, Silvestre LG, de Andrade DP, Lisboa LA, Jatene FB, Mejia OA, de estudos REPLICCAR G. Extubation in the operating room after coronary artery bypass graft surgery reduces hospital stay. *Journal of cardiothoracic and vascular anesthesia*. 2023 Oct 1;37(10):1938-45.
8. Flynn BC, He J, Richey M, Wirtz K, Daon E. Early extubation without increased adverse events in high-risk cardiac surgical patients. *The Annals of Thoracic Surgery*. 2023 Feb 1;107(2):453-9.

9. AR Y. Evaluation of nurses' participation in patient weaning from mechanical ventilation on the outcoms. *Medical-Surgical Nursing Journal*. 2012 Nov 15;1(1):6-10.
10. Martin S, Jackson K, Anton J, Tolpin DA. Pro: Early Extubation (< 1 Hour) After Cardiac Surgery Is a Useful, Safe, and Cost-Effective Method in Select Patient Populations. *Journal of Cardiothoracic and Vascular Anesthesia*. 2022 May 1;36(5):1487-90.
11. Etchill EW, Wu X, Alejo D, Fonner CE, Ling C, Worrall N, Lehr E, Pagani F, Haber T, Theurer P, Collins-Brandon J. A retrospective multicenter study of operating room extubation and extubation timing after cardiac surgery. *The Journal of thoracic and cardiovascular surgery*. 2024 Oct 18.
12. Chan JL, Miller JG, Murphy M, Greenberg A, Iraola M, Horvath KA. A multidisciplinary protocol-driven approach to improve extubation times after cardiac surgery. *The Annals of thoracic surgery*. 2024 Jun 1;105(6):1684-90.
13. Gregory AJ. Learning from failure: the future of quality improvement for early extubation. *Journal of Cardiothoracic and Vascular Anesthesia*. 2024 Jul 1;35(7):1971-3.
14. Johnson D, Thomson D, Mycyk T, Burbridge B, Mayers I. Respiratory outcomes with early extubation after coronary artery bypass surgery. *Journal of cardiothoracic and vascular anesthesia*. 2023 Jun 1;11(4):474-80.
15. James L, Smith DE, Galloway AC, Paone D, Allison M, Shrivastava S, Vaynblat M, Swistel DG, Loulmet DF, Grossi EA, Williams MR. Routine extubation in the operating room after isolated coronary artery bypass. *The Annals of Thoracic Surgery*. 2024 Jan 1;117(1):87-94.
16. Richey M, Mann A, He J, Daon E, Wirtz K, Dalton A, Flynn BC. Implementation of an early extubation protocol in cardiac surgical patients decreased ventilator time but not intensive care unit or hospital length of stay. *Journal of cardiothoracic and vascular anesthesia*. 2022 Apr 1;32(2):739-44.
17. Tham YC, Tan Z, Tam AL, Sharad SS, Sin KY, Chia SY, Ong KK. Improving on fast-track protocol for post cardiac surgery patients. *Journal of Cardiothoracic Surgery*. 2025 Dec;10:1-.
18. Nguyen Q, Coghlan K, Hong Y, Nagendran J, MacArthur R, Lam W. Factors associated with early extubation after cardiac surgery: a retrospective single-

- center experience. *Journal of cardiothoracic and vascular anesthesia*. 2025 Jul 1;35(7):1964-70.
19. O'Riordan E, Keane C, Dowd N. Clinical audit of early extubation in a tertiary referral cardiac surgery unit. *Journal of Cardiothoracic and Vascular Anesthesia*. 2024 Oct 1;34:S56.
 20. Mohamed A, Elsayed M, Prabhu M, ElAdawy M, Eisa A. PROSPECTIVE ASSESSMENT OF EARLY EXTUBATION AS PER CS-ERAS GUIDELINES IN CARDIAC SURGICAL PATIENTS (CASE SERIES). *Journal of Cardiothoracic and Vascular Anesthesia*. 2024 Dec 1;38(12):11-2.
 21. Konstantakos AK, Lee JH. Optimizing timing of early extubation in coronary artery bypass surgery patients. *The Annals of Thoracic Surgery*. 2020 Jun 1;69(6):1842-5.
 22. Nagre AS, Jambures NP. Comparison of immediate extubation versus ultrafast tracking strategy in the management of off-pump coronary artery bypass surgery. *Annals of cardiac anaesthesia*. 2021 Apr 1;21(2):129-33.
 23. Nicholson DJ, Kowalski SE, Hamilton GA, Meyers MP, Serrette C, Duke PC. Postoperative pulmonary function in coronary artery bypass graft surgery patients undergoing early tracheal extubation: a comparison between short-term mechanical ventilation and early extubation. *Journal of cardiothoracic and vascular anesthesia*. 2002 Feb 1;16(1):27-31.
 24. Nicholson DJ, Kowalski SE, Hamilton GA, Meyers MP, Serrette C, Duke PC. Postoperative pulmonary function in coronary artery bypass graft surgery patients undergoing early tracheal extubation: a comparison between short-term mechanical ventilation and early extubation. *Journal of cardiothoracic and vascular anesthesia*. 2002 Feb 1;16(1):27-31.
 25. Johnson D, Thomson D, Mycyk T, Burbridge B, Mayers I. Respiratory outcomes with early extubation after coronary artery bypass surgery. *Journal of cardiothoracic and vascular anesthesia*. 1997 Jun 1;11(4):474-80.
 26. Cheng DC, Karski J, Peniston C, Asokumar B, Raveendran G, Carroll J, Nierenberg H, Roger S, Mickle D, Tong J, Zelovitsky J. Morbidity outcome in early versus conventional tracheal extubation after coronary artery bypass grafting: a prospective randomized controlled trial. *The Journal of thoracic and cardiovascular surgery*. 1996 Sep 1;112(3):755-64.

27. Quasha AL, Loeber N, Feeley TW, Ulliyot DJ, Roizen MF. Postoperative respiratory care: a controlled trial of early and late extubation following coronary-artery bypass grafting. *Anesthesiology*. 1980 Feb;52(2):135-41.
28. Miyamoto T, Kimura T, Hadama T. The benefits and new predictors of early extubation following coronary artery bypass grafting. *Annals of Thoracic and Cardiovascular Surgery: Official Journal of the Association of Thoracic and Cardiovascular Surgeons of Asia*. 2000 Feb 1;6(1):39-45.
29. Walthall H, Robson D, Ray S. Do any preoperative variables affect extubation time after coronary artery bypass graft surgery?. *Heart & lung*. 2001 May 1;30(3):216-24.
30. Ingersoll GL, Grippi MA. Preoperative pulmonary status and postoperative extubation outcome of patients undergoing elective cardiac surgery. *Heart & Lung: the Journal of Critical Care*. 1991 Mar 1;20(2):137-43.
31. Reyes A, Vega G, Blancas R, Morato B, Moreno JL, Torrecilla C, Cereijo E. Early vs conventional extubation after cardiac surgery with cardiopulmonary bypass. *Chest*. 1997 Jul 1;112(1):193-201.
32. Lee TW, Jacobsohn E. Pro: tracheal extubation should occur routinely in the operating room after cardiac surgery. *Journal of cardiothoracic and vascular anesthesia*. 2000 Oct 1;14(5):603-10.
33. Reis J, Mota JC, Ponce P, Costa-Pereira A, Guerreiro M. Early extubation does not increase complication rates after coronary artery bypass graft surgery with cardiopulmonary bypass. *European journal of cardio-thoracic surgery*. 2002 Jun 1;21(6):1026-30.
34. London MJ, Shroyer AL, Coll JR, MaWhinney S, Fullerton DA, Hammermeister KE, Grover FL. Early extubation following cardiac surgery in a veterans population. *Anesthesiology*. 1998 Jun 1;88(6):1447-58.
35. Cheng DC, Karski J, Peniston C, Raveendran G, Asokumar B, Carroll J, David T, Sandler A. Early tracheal extubation after coronary artery bypass graft surgery reduces costs and improves resource use. A prospective, randomized, controlled trial. *Anesthesiology*. 1996 Dec 1;85(6):1300-10.
36. Habib RH, Zacharias A, Engoren M. Determinants of prolonged mechanical ventilation after coronary artery bypass grafting. *The Annals of thoracic surgery*. 1996 Oct 1;62(4):1164-71.

37. Doering LV, Imperial-Perez F, Monsein S, Esmailian F. Preoperative and postoperative predictors of early and delayed extubation after coronary artery bypass surgery. *American Journal of Critical Care*. 1998;7(1):37.
38. Ji Q, Chi L, Mei Y, Wang X, Feng J, Cai J, Sun Y. Risk factors for late extubation after coronary artery bypass grafting. *Heart & Lung*. 2010 Jul 1;39(4):275-82.
39. Plümer H, Markewitz A, Marohl K, Bernutz C, Weinhold C. Early extubation after cardiac surgery: a prospective clinical trial including patients at risk. *The Thoracic and cardiovascular surgeon*. 1998 Oct;46(05):275-80.
40. Camp SL, Stamou SC, Stiegel RM, Reames MK, Skipper ER, Madjarov J, Velardo B, Geller H, Nussbaum M, Geller R, Robicsek F. Can timing of tracheal extubation predict improved outcomes after cardiac surgery?. *HSR proceedings in intensive care & cardiovascular anesthesia*. 2009;1(2):39.
41. Michalopoulos A, Nikolaides A, Antzaka C, Deliyanni M, Smirli A, Geroulanos S, Papadimitriou L. Change in anaesthesia practice and postoperative sedation shortens ICU and hospital length of stay following coronary artery bypass surgery. *Respiratory medicine*. 1998 Aug 1;92(8):1066-70.
42. Hickey RF, Cason BA. Timing of tracheal extubation in adult cardiac surgery patients. *Journal of cardiac surgery*. 1995 Jul;10(4):340-8.
43. Suematsu Y, Sato H, Ohtsuka T, Kotsuka Y, Araki S, Takamoto S. Predictive risk factors for delayed extubation in patients undergoing coronary artery bypass grafting. *Heart and vessels*. 2000 Sep;15(5):214-20.
44. Cywinski JB, Xu M, Sessler DI, Mason D, Koch CG. Predictors of prolonged postoperative endotracheal intubation in patients undergoing thoracotomy for lung resection. *Journal of cardiothoracic and vascular anesthesia*. 2009 Dec 1;23(6):766-9.
45. Konstantakos AK, Lee JH. Optimizing timing of early extubation in coronary artery bypass surgery patients. *The Annals of thoracic surgery*. 2000 Jun 1;69(6):1842-5.
46. Nozawa E, Azeka E, Feltrim Z, Júnior JO. Factors associated with failure of weaning from long-term mechanical ventilation after cardiac surgery. *International heart journal*. 2005;46(5):819-31.

47. Rashid A, Sattar KA, Dar MI, Khan AB. Analyzing the outcome of early versus prolonged extubation following cardiac surgery. *Ann Thorac Cardiovasc Surg.* 2008 Aug 1;14(4):218-3.
48. John LC, Ervine IM. A study assessing the potential benefit of continued ventilation during cardiopulmonary bypass. *Interactive Cardiovascular and thoracic surgery.* 2008 Feb 1;7(1):14-7.
49. Cheng DC. Impact of early tracheal extubation on hospital discharge. *Journal of cardiothoracic and vascular anesthesia.* 1998 Dec 1;12(6 Suppl 2):35-40.
50. Grocott HP. Early extubation after cardiac surgery: The evolution continues. *The Journal of thoracic and cardiovascular surgery.* 2017 Nov 1;154(5):1654-5.
51. Jian L, Sheng S, Min Y, Zhongxiang Y. Risk factors for endotracheal re-intubation following coronary artery bypass grafting. *Journal of cardiothoracic surgery.* 2013 Nov 9;8(1):208.
52. Chamchad D, Horrow JC, Nakhamchik L, Sutter FP, Samuels LE, Trace CL, Ferdinand F, Goldman SM. The impact of immediate extubation in the operating room after cardiac surgery on intensive care and hospital lengths of stay. *Journal of cardiothoracic and vascular anesthesia.* 2010 Oct 1;24(5):780-4.
53. Salah M, Hosny H, Salah M, Saad H. Impact of immediate versus delayed tracheal extubation on length of ICU stay of cardiac surgical patients, a randomized trial. *Heart, lung and vessels.* 2015;7(4):311.
54. e Silva RA, Borgomoni GB, Maia AD, do Vale Juniora CF, Pereira ED, Silvestre LG, de Andrade DP, Lisboa LA, Jatene FB, Mejia OA, de estudos REPLICCAR G. Extubation in the operating room after coronary artery bypass graft surgery reduces hospital stay. *Journal of cardiothoracic and vascular anesthesia.* 2023 Oct 1;37(10):1938-45.
55. Nguyen Q, Coghlan K, Hong Y, Nagendran J, MacArthur R, Lam W. Factors associated with early extubation after cardiac surgery: a retrospective single-center experience. *Journal of cardiothoracic and vascular anesthesia.* 2021 Jul 1;35(7):1964-70.

56. Royse CF, Royse AG, Soeding PF. Routine immediate extubation after cardiac operation: a review of our first 100 patients. *The Annals of thoracic surgery*. 1999 Oct 1;68(4):1326-9.
57. Royse CF, Royse AG, Soeding PF. Routine immediate extubation after cardiac operation: a review of our first 100 patients. *The Annals of thoracic surgery*. 1999 Oct 1;68(4):1326-9.
58. Siliciano D. Con: Early extubation is not preferable to late extubation in patients undergoing coronary artery surgery. *Journal of Cardiothoracic and Vascular Anesthesia*. 1992 Aug 1;6(4):494-8.
59. Moradian ST, Beitollahi F, Ghiasi MS, Vahedian-Azimi A. Capnography and Pulse Oximetry Improve Fast Track Extubation in Patients Undergoing Coronary Artery Bypass Graft Surgery: A Randomized Clinical Trial. *Frontiers in Surgery*. 2022 May 11;9:826761.
60. Moradian ST, Beitollahi F, Ghiasi MS, Vahedian-Azimi A. Capnography and Pulse Oximetry Improve Fast Track Extubation in Patients Undergoing Coronary Artery Bypass Graft Surgery: A Randomized Clinical Trial. *Frontiers in Surgery*. 2022 May 11;9:826761.

APPENDICES
APPENDIX-1
Ethical Approval Letters



OFFICE OF THE DEAN-FAHS

SUPERIOR UNIVERSITY

Ref.: IRB /FAHS/Allied/10/25/MS/AHS-3834

Date: 10th October 2025

Name: Amad Khan

Registration: SU91-MSAHW-S24-042

Subject: Ethical Approval Letter

The Research Ethical Committee convened on Dated: 3rd October, 2025 to discuss your protocol titled "Comparison of capnography and arterial blood gases for prediction of early extubation patients undergoing coronary artery bypass graft surgery"

No further corrections and recommendations were suggested. The above-mentioned protocol has been approved after considering various research issues including ethical concerns with condition that the researcher will submit completion report at the end of his/her research.

Prof. Dr. Muhammad Naveed Babur
Dean/Convener REC
Faculty of Allied Health Sciences
Superior University, Lahore

August 25, 2025
Reference No HLH/ADM/IRB/2025-024

To,

Ethics Committee
Hameed Latif Hospital
Lahore.

Ethics Committee: 1. Prof. Dr. Farrukh Zaman
2. Prof. Dr. Javed Gardezi

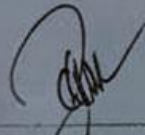
Subject: IRB Approval for Research

Topic: "Comparison of Capnography and Arterial Blood Gases for Prediction of Early Extubation in Patients Undergoing Coronary Artery Bypass Graft Surgery"

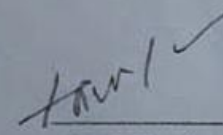
Dear Sir.

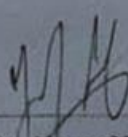
The application for the above mentioned study by Anesthesia Technologist Amad Khan "Comparison of Capnography and Arterial Blood Gases for Prediction of Early Extubation in Patients Undergoing Coronary Artery Bypass Graft Surgery" is submitted for your review and approval.

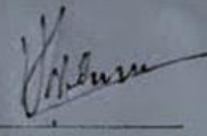
Approved ☒ Not Approved ☐

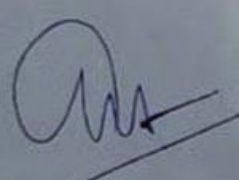

Prof. Dr. Farrukh Zaman

Approved ☒ Not Approved ☐


Prof. Dr. Javed Gardezi


Prof. Dr. Yousaf Lutf Khan
Clinical Director


Dr. Passaan Khan
Chief Operating Officer


Col (R) Dr Azhar Hayat
Associate Medical Director

APPENDIX-2

INFORMED CONSENT

“Comparison of capnography and arterial blood gases for prediction of early extubation patients undergoing coronary artery bypass graft surgery”

Informed Consent Form

Study

Title:

Comparison of capnography and arterial blood gases for prediction of early extubation patients undergoing coronary artery bypass graft surgery

Principal

Investigator:

Amad khan

Anesthesia technologist | Hameed Latif Hospital, Lahore

Purpose of the Study:

You are being invited to participate in a research study that aims to evaluate the effects of using capnography and pulse oximetry monitoring on the safety and timing of fast-track extubation after coronary artery bypass graft (CABG) surgery. This study will help improve monitoring practices in the intensive care unit (ICU) and potentially enhance recovery outcomes.

Procedures:

If you agree to participate, you will be randomly assigned to one of two groups. One group will be monitored using standard procedures, while the other group will be monitored using both capnography and pulse oximetry. Your vital signs and blood gas measurements will be closely monitored throughout the postoperative period. This study involves no changes to your surgery or anesthesia, and all procedures will follow standard clinical protocols.

Potential Risks and Discomforts:

There are no additional physical risks associated with this study beyond those involved in standard postoperative care. Monitoring devices are non-invasive and pose minimal risk. You may experience mild discomfort during routine blood gas sampling.

Potential Benefits:

Your participation may not directly benefit you, but the findings from this study could help improve the safety and efficiency of postoperative care for future patients undergoing similar surgeries.

Confidentiality:

All information collected during the study will remain strictly confidential. Your identity will not be disclosed in any reports or publications. Data will be stored securely and accessed only by authorized study personnel.

Voluntary Participation:

Your participation in this study is entirely voluntary. You may refuse to participate or withdraw at any time without affecting your medical care or legal rights.

Contact

Information:

If you have any questions or concerns about the study or your participation, you may contact:

Principal	Investigator:	Amad	Khan
Phone:			0341-5252376
Email:	amadk8108@gmail.com		

Participant Consent

I have read (or had read to me) the information provided above. I have had the opportunity to ask questions, and my questions have been answered to my satisfaction. I voluntarily agree to participate in this study.

Participant's **Name:** _____

Signature: _____ **Date:** _____

Investigator's **Name:** _____

Signature: _____ **Date:** _____

۶: اردو ترجمہ موجود ہے " (Informed Consent Form) رضامندی کا فارم " یقیناً، یہاں آپ کے مطالعہ کے لیے

مطالعہ کا عنوان:

(Principal Investigator):
کارفرما، ریاست اسناد و کتابخانه ملی جمهوری اسلامی ایران

مرحوم کا پہلا نام]]

[1] اداره / اسپتال / یونیورسٹی کا نام

مطالعہ کا مقصد:

آپ کو اس حقیقت میں شامل ہونے کی دعوت دی جا رہی ہے جس کا مقصد کارڈ کی ہر چہرہ کے بعد کچھ نغمہ رانی اور پاسنگ سرکس میں سرگودڑ سیر فاسٹ میں لکھنؤ ویڈیو میں شہل کی حفاظت اور کارڈ گیم کا جائزہ لینا ہے۔ یہ مطالعہ سرسبز و شاداب ہے۔

اگر آب اس حقیقت میں شامل ہونے پر رضامند ہوتے ہیں، تو آپ کو ترہماندار سکھ دے دو گروہو سے کہتا ہے کہ شامل کیا جائے گا۔
ایک گروہ کو معیار بطریقہ کار کے مطابق ماننے کا کہا جائے گا جبکہ دوسرے گروہ کو ایک دیگر انسانی اور پاسٹر سے پیشہ سکھ دے ماننے کا کہا جائے گا۔

ہوگے اور صرف نارمل خون (non-invasive) اس سے تھوڑی سی خاص جگہ پر خطرہ نہیں ہے۔ تمام مانیٹرنگ آلات غیر مداخلتی
 - کے ہر نوک پر جانچا جائے گا، جس سے کم سے کم تھوڑا سا خطرہ ہو سکتا ہے

نہ کہہ دوں

- آپ کو برابر برکویٹ فائدہ نہ پہنچے، لیکن اس حقیقت کے حاصل ہونے والے نتائج آئندہ ہر فرد کو علاج میں بہتری لاسکتے ہیں
رازداری

آپ کی تمام معلومات ہم رازدار کے ساتھ رکھ جائیں گی۔ آپ کی شناخت کو کسی دوسرے اشاعت میں ظاہر نہیں کیا جائے گا۔ صرف وچار
- حقیقتاً یہ ہماری ہمت کا ثبوت ہے کہ اس کے حاصل کر سکیں

نہ کہہ دوں

اس میں یہ یقین ہو کہ یہ سب کے سب رازدار کے لئے ہے۔ اگرچہ وہی وقت بعض سربراہان کے لئے بھی ہو سکتے ہیں۔ یہ آپ کے علاج کا قانون
- حقوق کو متاثر نہیں کرے گا

رازدار کی معلومات

اگر آپ کو حقیقتاً اس میں یقین ہو کہ ہمارے یہ سب کے سب رازدار کے لئے ہیں تو آپ کو ہمارے رازدار
کہیں نام []: حقیقتاً ہمارے

نہ کہہ دوں []: نہ کہہ دوں

[] یہ سب کے سب []: یہ سب کے سب

نہ کہہ دوں []: نہ کہہ دوں

میں نے اس حقیقت کو ہمارے تمام معلومات کو سنبھال دیا (میں نے سنبھال دیا) اور میرے رازدار کے لئے یہ سب کے سب ہیں۔

- ہمارے لئے اس حقیقت میں سب کے سب رازدار ہیں
نہ کہہ دوں []: نہ کہہ دوں

نہ کہہ دوں []: نہ کہہ دوں

نہ کہہ دوں []: نہ کہہ دوں

نہ کہہ دوں []: نہ کہہ دوں

APPENDIX-3

QUESTIONNAIRE

“Comparison of capnography and arterial blood gases for prediction of early extubation patients undergoing coronary artery bypass graft surgery”

Section 1: Demographic Characteristics

1. What is the patient's age? (in years) _____
2. What is the patient's gender?
 - ☐ Male
 - ☐ Female
3. What is the patient's Body Mass Index (BMI)? (kg/m²) _____
4. Does the patient have a history of smoking?
 - ☐ Yes
 - ☐ No
5. Does the patient have a history of opium use?
 - ☐ Yes
 - ☐ No

Section 2: Comorbidities

6. Does the patient have renal diseases?
 - ☐ Yes
 - ☐ No
7. Is the patient diagnosed with diabetes mellitus?
 - ☐ Yes
 - ☐ No
8. Is the patient diagnosed with hypertension?
 - ☐ Yes
 - ☐ No

Section 3: Clinical Characteristics

9. What is the patient's Ejection Fraction (EF)? (%) _____
10. What was the total pump time during surgery? (minutes) _____

11. Type of operation performed:

- ☐ Coronary Artery Bypass Graft (CABG)
- ☐ Other (specify)

12. What was the duration of operation (DO)? (minutes) _____

Section 4: Intraoperative Parameters

13. Record the following ventilation parameters:

Parameter	Baseline Value	Trigger Time	Extubation Time
Tidal Volume (VT), ml			
Inspiratory Pressure (Pi), cmH ₂ O			
FiO ₂ , %			
Positive End Expiratory Pressure (PEEP), cmH ₂ O			
Total Flow			
Controlled Flow			
Exhaled Tidal Volume (TVE)			

Section 5: Arterial Blood Gas (ABG) Measurements

14. Record the following ABG parameters:

Parameter	Baseline Value	Trigger Time	Extubation Time	Post-Extubation
Blood pH				
PaCO ₂ (mm Hg)				
PaO ₂ (mm Hg)				
SpO ₂ (%)				
Base Excess (BE), mm Hg				
HCO ₃ ⁻ (mEq/L)				

Section 6: Hemodynamic Parameters

15. Record the following haemodynamic parameters:

Parameter	Baseline	Trigger Time	Extubation Time	Post-Extubation
Heart Rate (bpm)				

Respiratory Rate (/min)				
Systolic BP (mm Hg)				
Diastolic BP (mm Hg)				
Mean Arterial Pressure (MAP), mm Hg				
SpO ₂ (%)				

Section 7: Postoperative Outcomes

16. Number of alarms triggered (mean $\pm$ SD): _____

17. Number of manipulations required (mean $\pm$ SD): _____

18. Time to extubation (minutes): _____

19. Length of ICU stay (days): _____

20. Was early extubation achieved (<6 hours)?

○ ☐ Yes

○ ☐ No