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Corresponding Author:
Dr. Asita Elengoe, Department of Biotechnology, Lincoln University College, Malaysia.
Email: elengoeasita@gmail.com

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Review Article

Respiratory Function and Arterial Blood Gas Outcomes in On-Pump versus Off-Pump Coronary Artery Bypass Graft Patients

Wajeeha Sahar[1], Asita Elengoe[1], Anjum Jalal[2], Hamza Azam[3], Mishel Tariq[3], Amina Shahbaz[3]

[1]Lincoln University College, Malaysia, [2]Punjab Institute of Cardiology, Pakistan, [3]The University of Lahore, Pakistan

Abstract

This review aims to compare the outcomes of preoperative respiratory rehabilitation in patients undergoing coronary artery bypass grafting (CABG) with cardiopulmonary bypass (on-pump) versus without cardiopulmonary bypass (off-pump). The focus is on the reduction of postoperative pulmonary complications (PPCs) and improvements in pulmonary function and arterial blood gases.

Seven randomized controlled trials (RCTs) met the inclusion criteria for this review, drawn from an initial screening of 13 citations. One study presented a combined analysis of two trials, resulting in data from seven distinct trials explicitly comparing pulmonary function and arterial blood gas outcomes between on-pump and off-pump CABG patients. Several studies emphasized the potential benefits of integrating preoperative respiratory rehabilitation with surgical approaches to improve patient outcomes.

Pulmonary dysfunction remains a significant adverse consequence of cardiopulmonary bypass (CPB), contributing to postoperative morbidity. Off-pump coronary artery bypass grafting (OPCAB) has gained popularity in recent years due to its association with fewer pulmonary complications. Multiple studies report marked improvements in postoperative pulmonary function tests in OPCAB patients, including higher oxygen saturation ($SpO2 > 95\%$) and reduced extubation times (<48 hours), compared to those undergoing on-pump CABG.

Preoperative respiratory rehabilitation in CABG patients significantly reduces the risk of PPCs, shortens hospital stays, and facilitates earlier extubation. These findings support the incorporation of respiratory rehabilitation, including inspiratory muscle training, into routine preoperative care to enhance patient recovery. Further research is needed to assess the efficacy of combined physiotherapy interventions in patients undergoing CABG.

Keywords: Cardiopulmonary Bypass, Preoperative Rehabilitation, Pulmonary Function, Off-Pump CABG, Postoperative Pulmonary Complications

INTRODUCTION

Coronary Artery Disease (CAD) is a leading cause of mortality globally, particularly in developed nations, primarily attributed to lifestyle factors such as obesity and physical inactivity [1]. Coronary Artery Bypass Graft (CABG) surgery, a standard treatment for CAD, significantly improves survival and ventricular function. However, it is associated with a substantial risk of postoperative pulmonary complications (PPCs) like pneumonia, atelectasis, respiratory failure, pneumothorax, and bronchospasm. Despite advancements that have reduced mortality rates, PPCs remain a major concern, leading to prolonged hospitalization, increased healthcare costs, and psychological impacts such as anxiety [2].

Cardiac surgery, including CABG and heart valve replacement, often becomes necessary when other treatments fail. Despite the use of advanced surgical techniques and materials, the risk of complications remains high, with rates ranging from 5% to 90%, depending on the classification system used [3,4]. PPCs occur due to factors such as anesthesia, surgical trauma, and postoperative pain, which limit chest movement and lung expansion. Studies indicate that up to 70% of patients undergoing cardiac surgery experience complications, including lung atelectasis, pulmonary dysfunction, pleural effusion, and hypoxemia [5]. These complications significantly contribute to increased morbidity and healthcare burdens.

Patients with preoperative respiratory dysfunction face a heightened risk of requiring mechanical ventilation after cardiac surgery. Reduced respiratory muscle strength has been identified as a critical factor impairing functional recovery after CABG [6,7]. Early concerns about pulmonary function following CABG emerged with the development of cardiopulmonary bypass (CPB) in the 1950s and 1960s. Research has demonstrated that pulmonary function is more adversely affected in on-pump CABG than in off-pump procedures [8,9]. For instance, pulmonary complications have been reported in 9.7% of on-pump cases compared to 3.2% in off-pump cases [10].

Preoperative inspiratory muscle training (IMT) has been shown to significantly reduce PPCs. However, its routine application in clinical practice remains inconsistent across regions. Studies have highlighted that preoperative IMT improves inspiratory muscle strength, decreases the incidence of PPCs, and shortens hospital stays after surgery [11]. Postoperative pulmonary dysfunction following CABG often manifests as impaired gas exchange, decreased lung volumes, and weakened inspiratory effort, which can complicate recovery [12].

A variety of interventions, including incentive spirometry, positive pressure exercises, and chest physiotherapy, are employed to mitigate PPCs. However, evidence supporting their effectiveness remains limited and variable. Research has shown that PPCs such as atelectasis frequently occur in lung regions near the diaphragm, suggesting that targeted IMT can improve lung expansion and regional ventilation [13-15].

Recent studies have investigated the role of preoperative rehabilitation in enhancing recovery and reducing complications after CABG. For instance, one study demonstrated that a four-phase physiotherapy regimen improved functional ability, as assessed by the 6-minute walk test, and reduced ICU stays [16]. Similarly, another study involving 952 patients found that preoperative IMT reduced ventilation duration and the incidence of postoperative pneumonia [17-25].

This review systematically examines the effects of CABG—both on-pump and off-pump—on postoperative respiratory function, with a focus on arterial blood gases and pulmonary mechanics. By comparing these surgical approaches, it aims to provide insights into their impact on patient recovery and respiratory stability, guiding surgical decision-making and postoperative care strategies.

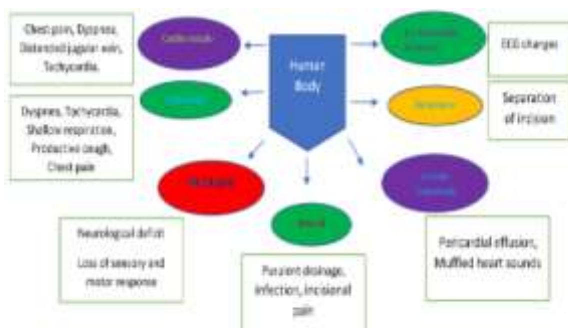

Figure 1: Following Complications in CABG patients [26]

METHODOLOGY

Eligibility Criteria: The inclusion criteria for this systematic review were as follows:

1. Randomized controlled trials (RCTs) involving adult patients undergoing elective cardiac surgery, including coronary artery bypass grafting (CABG) with or without cardiopulmonary bypass (CPB).

2. Studies that reported outcomes related to postoperative pulmonary complications (PPC) or length of hospital stay (LHS).

3. Trials comparing off-pump coronary artery bypass (OPCAB) and traditional CABG.

Exclusion criteria included studies involving hybrid procedures (e.g., OPCAB with balloon angioplasty), robotic-assisted surgeries, or those using circulatory support devices. Non-randomized trials, case reports, and studies focusing on outcomes unrelated to pulmonary complications or hospital stay were also excluded [27,28].

Information Sources: The literature search included multiple databases to ensure a comprehensive identification of relevant studies. These databases comprised MEDLINE, EMBASE, CINAHL, Cochrane Clinical Answers, Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, Current Contents, Scientific Citation Index, and the NHS Economic Evaluation Database. To supplement the electronic search, reference lists of included studies, citations, and related systematic reviews were manually screened to identify additional studies that might have been missed during the database search [29].

Search Strategy: A comprehensive search strategy was employed, incorporating terms for the population, intervention, and outcomes. The population search terms included: *"heart surgery"* and *"cardiac surgery."* The intervention was defined by terms such as *"preoperative," "inspiratory muscle training," "breathing exercises,"* and *"breathing treatment."* The outcomes were captured using terms like *"length of stay," "postoperative pulmonary complications,"* and *"cardiopulmonary bypass."*

The search incorporated both Medical Subject Headings (MeSH) terms and free-text keywords to maximize sensitivity. Searches were restricted to studies published from October 2019 onwards and included studies in all languages, with translations arranged where needed.

Selection Process: The selection process followed PRISMA guidelines. Titles and abstracts identified through the database search were independently screened by two reviewers. Articles deemed potentially eligible were retrieved in full text for further review. Discrepancies between reviewers were resolved through discussion or by consulting a third reviewer. A PRISMA flow diagram illustrates the selection process.

Data Collection Process: Data extraction was carried out independently by two reviewers using a standardized data collection form to ensure accuracy and consistency. The extracted data included study details such as author, year, and study design; participant characteristics like age, comorbidities, and surgical risk; intervention specifics, comparing OPCAB with CABG performed on CPB; and reported outcomes, including postoperative pulmonary function, length of hospital stay (LHS), and postoperative pulmonary complications (PPC). Additionally, key findings and statistical analyses were recorded. Any discrepancies identified during the data extraction process were resolved through consensus, with a third reviewer consulted when necessary to reach a final agreement.

Data Items: The primary outcomes of interest were PPC incidence and length of hospital stay. Secondary outcomes included measures of pulmonary function, extubation time, and dynamic and static lung compliance. Additional data, such as intervention protocols, patient demographics, and study funding sources, were also collected to contextualize the findings.

Study Risk of Bias Assessment: The methodological quality of the included studies was assessed using the Cochrane Risk of Bias Tool (RoB 2.0). Each study was systematically evaluated across key domains, including the randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and the selection of reported results. Based on these evaluations, studies were categorized as having a low risk of bias, a high risk of bias, or as raising some concerns regarding bias.

Effect Measures: For dichotomous outcomes, odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. For continuous outcomes, weighted mean differences (WMDs) with 95% CIs were used. Data synthesis was performed using meta-analytic techniques where feasible.

Synthesis Methods: A narrative synthesis was conducted for studies that were not amenable to meta-analysis. Where pooling was possible, meta-analyses were conducted using a random-effects model to account for heterogeneity across studies. Statistical heterogeneity was assessed using the I^2 statistic, with values of 25%, 50%, and 75% representing low, moderate, and high heterogeneity, respectively. Subgroup analyses were performed based on patient risk profiles and baseline pulmonary function.

Reporting Bias Assessment: To evaluate potential reporting biases, funnel plots were constructed for meta-analyses with at least ten studies. Egger's test was employed to assess asymmetry. Publication bias was minimized by including non-English studies and performing manual searches of conference abstracts and bibliographies.

Table 1: Evaluation of the degree of evidence and recommendations [30]

Grade A	
Level 1a	Proof from a large number of RCTs or systematic reviews, some of which may contain meta-analyses of several RCTs.
Level 1b	Evidence from a minimum of one excellent cohort research.
Level 1c	Evidence from a meta-analysis of small studies with just a moderate total number of patients or from at least one moderate-sized randomized controlled trial (RCT).
Level 1d	Proof from a minimum of one RCT
Grade B	
Level 2	Evidence from a minimum of one excellent trial involving nonrandomized cohorts that were given the new medication and those that weren't
Level 3	Evidence from one or more excellent studies of case-control
Grade C	
Level 4	Proof after a minimum of first set of outstanding cases
Grade D	
Level 5	Professional judgments

RESULTS

Study Selection: A total of 13 citations were screened, and 7 randomized controlled trials (RCTs) met the inclusion criteria for detailed evaluation. One of the included studies presented a combined analysis of two trials. Additionally, three systematic reviews and four meta-analyses relevant to the research question were identified. Among the RCTs, seven directly compared the effects of off-pump coronary artery bypass (OPCAB) versus conventional coronary artery bypass grafting (CABG) with cardiopulmonary bypass (CPB) on postoperative pulmonary dysfunction. However, none of the meta-analyses specifically assessed postoperative pulmonary dysfunction following these myocardial revascularization techniques.

Study Characteristics: The included studies varied in terms of patient populations, surgical risk profiles, and the presence or absence of preexisting pulmonary conditions. The sample sizes ranged from 18 to 100 per group. Most trials focused on elective primary CABG surgery, with some including patients with obstructive or restrictive pulmonary diseases, while others examined low-risk or multivessel patients. The trials used various pulmonary function parameters such as arterial blood gases (ABGs), forced expiratory volume (FEV1), forced vital capacity (FVC), and pulmonary compliance to evaluate outcomes. A summary of the study characteristics is presented in Table 2 [31,32].

Risk of Bias in Studies: The methodological quality of the included studies revealed certain limitations. Notably, none of the trials were double-blinded. Some studies had small sample sizes, which may impact the robustness of the findings. However, all studies provided sufficient details regarding randomization and outcome measurements. The potential risk of selection and performance bias was acknowledged.

Results of Individual Studies

Among the RCTs, outcomes varied across patient populations:

- OPCAB was associated with increased partial pressure of oxygen (PaO_2), quicker extubation times, and decreased postoperative pulmonary compliance in unselected patients undergoing primary CABG surgery ($p = 0.001$) [33].
- In hemodynamically stable patients without pulmonary diseases, OPCAB did not show significant improvements in pulmonary function or ABGs [34].
- Significant reductions in pulmonary compliance and intrapulmonary shunting were observed in low-risk patients undergoing OPCAB ($p < 0.05$) [35].

- For patients with obstructive or restrictive pulmonary disease, OPCAB led to a better postoperative clinical course and shorter ventilation times ($p = 0.03$) [36].
- Patients with severe chronic obstructive pulmonary disease (COPD) undergoing CABG/CPB showed significantly lower FEV1/FVC ratios and reduced FEV1 levels in the second postoperative month ($p < 0.05$) [37].
- In multivessel, low-risk patients, OPCAB resulted in quicker extubation (8.2 hours vs. 9.2 hours) and improvements in static and dynamic lung compliance ($p = 0.06$) [14].
- Comparably, both OPCAB and CABG showed similar levels of respiratory failure in low-risk patients without documented pulmonary conditions [38].

Results of Syntheses: A meta-analysis by Cheng et al., which included 7 RCTs, demonstrated that OPCAB significantly reduced postoperative respiratory illness compared to CABG/CPB. The weighted mean difference (WMD) in extubation time was -3.4 hours (95% CI, -5.0 to -1.7), and the odds ratio (OR) for respiratory illnesses was 0.41 (95% CI, 0.23–0.74), with a number needed to treat (NNT) of 19 (95% CI, 12–52). These findings highlight OPCAB's potential benefits in reducing certain pulmonary complications following surgery [32].

Reporting Biases: The systematic evaluation did not identify significant reporting biases; however, the lack of double-blinded trials and the heterogeneity in outcome reporting might have contributed to variability in the results.

Certainty of Evidence: The certainty of evidence was moderate to low across the included studies, primarily due to the small sample sizes, lack of blinding, and variability in outcome measures. Future high-quality trials with standardized outcome reporting are warranted to confirm these findings and provide more definitive evidence.

DISCUSSION

Conventional CABG involves the use of CPB to operate on a non-beating, cardioplegic heart, offering surgeons greater control and precision when addressing multiple coronary arteries. This technique has become the gold standard for myocardial revascularization. However, CPB triggers a systemic inflammatory response when circulating blood comes into contact with the extracorporeal circuit of the heart-lung machine. This response activates cellular and humoral mediators, resulting in complications such as coagulopathy, respiratory failure, renal dysfunction, postoperative myocardial infarction, and neurological complications [39].

Postoperative pulmonary dysfunction is a recognized concern associated with CPB. Clinical presentations range from asymptomatic functional abnormalities to acute respiratory distress syndrome (ARDS), which occurs in less than 2% of patients but has a mortality rate exceeding 50%. The pathophysiology involves impaired lung mechanics and gas exchange, including increased pulmonary vascular resistance, shunting, microvascular permeability, and alveolar-arterial oxygen gradient expansion. Lung mechanical changes, such as decreased compliance and reduced functional residual capacity, further contribute to postoperative pulmonary dysfunction [40].

The Case for OPCAB: The off-pump coronary artery bypass (OPCAB) approach was developed to mitigate the complications of CPB. By avoiding CPB altogether, OPCAB reduces the systemic inflammatory response, potentially leading to fewer complications such as atelectasis, pleural effusion, and diaphragm dysfunction. OPCAB does not rely on CPB-dependent triggers such as neutrophil and platelet activation, complement cascade activation, and oxidative stress, which are central to postoperative pulmonary dysfunction [41].

Our systematic review identified seven RCTs that specifically examined the impact of OPCAB on postoperative pulmonary outcomes compared to traditional CABG. These studies consistently demonstrated that OPCAB is associated with better preservation of pulmonary function, quicker extubation, and reduced incidence of pulmonary complications. For example, Staton et al. (2020) showed that OPCAB resulted in improved gas exchange and a shorter duration of mechanical ventilation, albeit without significant differences in rates of pleural effusion, pneumonia, or reintubation between OPCAB and traditional CABG groups. Interestingly, the study noted that OPCAB patients experienced greater reductions in static respiratory compliance postoperatively, likely due to the need for heart manipulation during surgery [42].

Role of Inspiratory Muscle Training (IMT): An adjunctive strategy to optimize postoperative outcomes is inspiratory muscle training (IMT). This technique involves resistance-based breathing exercises to strengthen the inspiratory muscles. Studies have demonstrated that IMT enhances inspiratory muscle strength and endurance, leading to faster extubation, shorter mechanical ventilation durations, and improved overall pulmonary function. IMT also contributes to better psychosocial well-being, reduced postoperative complications like pneumonia, and improved functional recovery [43,44].

Insights for COPD and High-Risk Patients: Patients with pre-existing pulmonary conditions, such as chronic obstructive pulmonary disease (COPD), benefit significantly from OPCAB. Several RCTs, including those by Guler et al. (2018) and Covino et al. (2017), showed that OPCAB substantially reduced atelectasis, ICU stays, and intubation duration compared to traditional CABG in COPD patients. Additionally, forced expiratory volumes and vital capacities were better preserved in the OPCAB group, underscoring its pulmonary protective effects [43,44].

For certain high-risk populations, the MIDCAB (minimally invasive direct coronary artery bypass) technique may offer an alternative to mitigate both CPB- and sternotomy-related complications. This approach is particularly beneficial for patients with severe pulmonary disease, where minimizing surgical trauma and avoiding CPB are critical to postoperative recovery.

CONCLUSION

Evidence from RCTs indicates that OPCAB is superior to traditional CABG for patients prone to postoperative pulmonary complications, especially those with COPD. OPCAB minimizes respiratory dysfunction by avoiding CPB-induced changes such as increased alveolar-capillary permeability, complement activation, and oxidative stress. For high-risk patients, adopting OPCAB or MIDCAB approaches may lead to better clinical outcomes, reduced hospital stays, and improved quality of life post-surgery. Future studies should focus on long-term pulmonary outcomes and explore patient-centered strategies, such as IMT, to further enhance recovery trajectories in CABG patients.

AUTHORS' CONTRIBUTION

WS, AE, AJ, HA, MT, and AS: Concept and design, data acquisition, interpretation, drafting, final approval, and agree to be accountable for all aspects of the work. WS, AE, AJ, HA, MT, and AS: Data acquisition, interpretation, drafting, final approval and agree to be accountable for all aspects of the work.

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