

# Effectiveness of Active Cycle of Breathing Technique in Improving Physiological and Functional Outcomes Following Coronary Artery Bypass Graft Surgery: A Narrative Review

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**Abstract:** Coronary artery bypass grafting (CABG) is a common surgical approach for advanced coronary artery disease unresponsive to conservative or percutaneous treatments. Despite its benefits in symptom relief and long-term outcomes, CABG is associated with notable postoperative respiratory complications. As such, respiratory physiotherapy plays a crucial role in recovery. The active cycle of breathing technique (ACBT) is a non-invasive, evidence-based method that promotes lung ventilation, secretion clearance, and respiratory function. This review aimed to describe the effectiveness of the ACBT in enhancing physiological and functional outcomes following CABG surgery. A review of PubMed and Google Scholar studies was conducted, with relevant articles analyzed for study design, patient profiles, intervention protocols, and clinical outcomes. Fifteen articles were included, encompassing studies on pulmonary complications following CABG, dosage and application of ACBT, its preventive role in postoperative pulmonary complications (PPCs), and its effects on respiratory and functional outcomes. The results of this review are expected to enhance clinicians' insight into selecting physical therapy to prevent PPCs. Pulmonary complications, including atelectasis and impaired gas exchange, are common after CABG and are primarily associated with anesthesia, surgical trauma, systemic inflammatory response, and impaired airway clearance. ACBT, consisting of breathing control, thoracic expansion, and forced expiration techniques, is a structured, non-invasive intervention designed to mobilize secretions and improve ventilation. It is typically applied 2–3 times per day over 2–5 days and often combined with incentive spirometry and conventional chest physiotherapy. The reviewed studies suggest that ACBT enhances oxygenation, improves lung volumes, and increases functional capacity. Additionally, ACBT helps reduce postoperative pain and dyspnea, contributing to overall recovery without reported adverse events. To conclude, ACBT is a safe, practical, and effective physiotherapeutic approach to support postoperative pulmonary recovery in CABG patients. Further well-designed trials are needed to validate and standardize its clinical use.

**Keywords:** coronary artery bypass, dyspnea, post-operative pain, pulmonary atelectasis, spirometry

## Introduction

Coronary artery bypass graft (CABG) surgery is one of the most frequently performed cardiac procedures for managing advanced coronary artery disease unresponsive to medical therapy or percutaneous interventions.<sup>1</sup> While CABG effectively improves symptoms and long-term survival, it is associated with a high risk of postoperative pulmonary complications (PPCs), including atelectasis, pneumonia, and hypoxemia, primarily due to anesthesia, thoracotomy, cardiopulmonary bypass, and pain-related hypoventilation.<sup>2,3</sup> These complications can negatively affect functional performance and pulmonary capacity, both at discharge and up to six months postoperatively, highlighting the need for structured rehabilitation.<sup>4,5</sup>

Respiratory physiotherapy is an integral component of post-CABG care, aimed at reducing PPC incidence and enhancing pulmonary recovery.<sup>6</sup> One widely adopted technique is the active cycle of breathing technique (ACBT), which integrates breathing control (BC), thoracic expansion exercises (TEE), and forced expiration technique (FET) or huffing to mobilize secretions and improve ventilation.<sup>7,8</sup> ACBT has demonstrated effectiveness in patients with chronic respiratory conditions and those recovering from major abdominal or thoracic surgeries.<sup>9–11</sup>

In contrast to incentive spirometry (IS), positive expiratory pressure (PEP) therapy, or manual chest physiotherapy, ACBT provides a more active and comprehensive airway clearance approach.<sup>7,10</sup> However, its relative effectiveness and clinical utility in CABG patients remain uncertain. While some studies report improvements in peak expiratory flow (PEF), inspiratory capacity (IC), and pain reduction, others found no significant benefit over conventional physiotherapy.<sup>12,13</sup>

Notably, the current literature on ACBT in CABG is limited, inconsistent, and methodologically heterogeneous. For example, several studies found no differences between ACBT and IS or routine chest physiotherapy in gas exchange or PPC prevention, whereas others reported improvements in forced expiratory volume in one second (FEV<sub>1</sub>), breath-holding time, and partial pressure of carbon dioxide (PaCO<sub>2</sub>).<sup>14–17</sup> These discrepancies may be due to small sample sizes, short intervention durations (typically 2–5 days), and heterogeneous control interventions. Moreover, few studies have evaluated its long-term impact or role in later cardiac rehabilitation phases, and no consensus exists on which patient subgroups benefit most.

This narrative review seeks to address this evidence gap by critically summarizing and contextualizing the existing literature on the use of ACBT in patients undergoing CABG surgery. It aims to evaluate its physiological and functional outcomes, explore mechanisms of benefit, and identify directions for future research to inform clinical decision-making.

## Methods

A narrative literature review was conducted to synthesize evidence on the application of the ACBT in patients undergoing CABG surgery. The search strategy included peer-reviewed articles indexed in PubMed and Google Scholar, using the following search terms: “active cycle of breathing technique” OR “ACBT” OR “breathing exercise” AND “coronary artery bypass graft” OR “CABG” OR “cardiac surgery”. Articles were included if they met the following criteria: 1) Original research studies and reviews evaluating the effectiveness or clinical impact of ACBT in post-CABG patients; 2) Written in English or Indonesian; and 3) Available in full-text format. Articles were excluded if they did not involve CABG, as “cardiac surgery” was the primary keyword used.

The initial search results were screened for duplicate entries, which were then removed. The remaining records were screened independently by title, abstract, and keywords to assess relevance. Articles that matched the inclusion criteria were subjected to full-text review. Reference lists and citation networks of selected studies were also examined to identify any additional relevant articles (backward and forward citation tracking).

From the final selection of eligible studies, the study design and setting, population characteristics, ACBT protocols or intervention characteristics (frequency, duration, and combinations with other therapies), and key findings were extracted. Data were synthesized descriptively and presented as text and tables to describe pulmonary complications after CABG surgery, ACBT, PPCs, and the role of ACBT, dosage and application of ACBT in post-CABG patients, and effects of ACBT on physiological parameters and functional outcomes.

## Results

A total of 11 articles were reviewed in this study, comprising six original research articles and five review articles. Pulmonary complications following CABG surgery were discussed in five articles, including two original studies and three reviews. The ACBT was specifically addressed in two reviews. The role of ACBT in preventing and managing PPCs was explored in three articles, two of which were original studies and one a review. Furthermore, four original articles examined the dosage, application, and clinical effects of ACBT on physiological parameters and functional outcomes in post-CABG patients. This body of literature provides a comprehensive understanding of both the pathophysiology of post-CABG pulmonary complications and the therapeutic potential of ACBT in addressing these issues.

## Discussion

### Pulmonary Complications After CABG Surgery

CABG is a major surgical procedure performed to improve cardiac function, enhance survival, and alleviate anginal symptoms by restoring blood flow to the ischemic myocardium. This is achieved by bypassing atherosclerotic blockages in the coronary arteries using venous or arterial grafts harvested from other parts of the body.<sup>1</sup> Significant advancements in both surgical techniques and perioperative management over the past several decades have contributed to a marked enhancement in surgical outcomes. These improvements have led to reductions in perioperative morbidity and mortality and have allowed cardiac surgeons to offer this procedure to a broader and often more complex patient population.<sup>18</sup> However, despite these medical and technological strides, PPCs remain prevalent, particularly those involving the pulmonary system.<sup>19</sup>

Pulmonary complications continue to represent some of the most common and clinically significant adverse events following CABG surgery. Even with the implementation of state-of-the-art surgical strategies and optimized perioperative care protocols, postoperative respiratory dysfunction remains a persistent and challenging issue. These complications can exert a profound influence on patient outcomes by increasing the risk of prolonged mechanical ventilation, intensive care unit stay, and hospital length of stay, as well as overall morbidity.<sup>1,19</sup>

A significant decline in pulmonary function commonly occurs following CABG, even in patients with normal preoperative respiratory status. The reductions involve key parameters such as forced vital capacity (FVC), forced expiratory volume in one second (FEV<sub>1</sub>), vital capacity (VC), inspiratory capacity (IC), peak expiratory flow rate (PEFR), functional residual capacity (FRC), total lung capacity (TLC), and diffusing capacity of the lungs for carbon monoxide (DLCO). FVC may decrease by as much as 29–33% on the first postoperative day, and several parameters remain impaired by 6–13% at three to four months after surgery, although some, such as residual volume (RV) and DLCO per alveolar volume (DLCO/VA), may return to baseline over time.<sup>20</sup>

The underlying mechanisms are multifactorial. Post-sternotomy pain plays a major role, as its severity correlates with pulmonary function trends and may persist for months, affecting deep breathing and coughing. Additional contributing factors include altered chest wall mechanics due to thoracic opening, reduced rib cage expansion, uncoordinated chest wall motion, respiratory muscle weakness, and basal atelectasis that often begins during anesthesia and extends into the postoperative period. Age has been identified as a strong predictor of long-term pulmonary dysfunction, and the type of graft used may influence the degree of impairment, with internal mammary artery grafts showing a trend toward greater FVC reduction compared to saphenous vein grafts, although this difference is not statistically significant. Other variables such as smoking history, cardiopulmonary bypass duration, and anesthetic technique appear to have minimal influence based on current evidence.<sup>20,21</sup>

Diminished strength in both inspiratory and expiratory muscles is frequently observed in the early postoperative period. Reductions in maximal inspiratory pressure and maximal expiratory pressure are indicative of this weakness and have been associated with a heightened risk of PPCs.<sup>21</sup>

The collective evidence underscores the intricate and interdependent mechanisms—mechanical, neuromuscular, and cardiopulmonary—that underlie postoperative pulmonary dysfunction following CABG surgery. This condition remains a critical determinant of patient recovery and prognosis. Accordingly, timely identification of patients at risk, combined with proactive and individualized physiotherapeutic interventions, is essential to minimize the incidence and severity of PPCs. Such interventions can play a pivotal role in improving pulmonary mechanics, enhancing functional capacity, and expediting overall recovery in the post-CABG patient population.

### ACBT

The ACBT is a widely recognized and evidence-based airway clearance strategy that is particularly valued for its simplicity and accessibility. One of the main advantages of ACBT is that it does not necessitate the use of specialized or costly medical equipment, making it especially suitable and feasible for a broad range of patients, including those in low-resource settings or recovering at home. This technique can be self-administered or guided by a therapist and is adaptable to various clinical and non-clinical environments, contributing to its widespread utility and patient adherence.<sup>9</sup>

ACBT consists of three distinct and sequential phases of breathing that are systematically performed to promote the mobilization and removal of pulmonary secretions (Table 1). Each phase is designed to serve a specific physiological purpose, working synergistically to improve ventilation, enhance airway clearance, and reduce respiratory effort. These phases include breathing control (BC), thoracic expansion exercise (TEE), and the forced expiration technique (FET), all of which are integral to the overall effectiveness of the intervention.<sup>9</sup>

This structured technique is typically performed in a seated or vertical position, which optimizes diaphragmatic movement and lung expansion. ACBT can be used as a stand-alone intervention or in combination with adjunctive airway clearance modalities, such as manual chest physiotherapy techniques—including percussion and vibration—or mechanical devices that assist secretion mobilization. The sitting position is generally considered the most effective posture for executing ACBT, as it promotes optimal thoracic expansion and ventilation distribution.<sup>22</sup>

However, the therapeutic efficacy of ACBT can be further enhanced by integrating gravity-assisted postural drainage techniques. These positions are selected based on the anatomical orientation of the bronchial tree and the targeted lung segments. For example, a 15-degree head-down tilt is commonly recommended for effective drainage of the right middle lobe, while a 20-degree tilt is suitable for targeting the lower lobes. These positional strategies leverage gravitational forces to facilitate mucus migration toward the central airways, where it can be expelled more efficiently during the forced expiration phase.<sup>22</sup>

It is important to recognize that certain patient populations may not tolerate head-down positions well. Conditions such as gastroesophageal reflux disease, hypertension, or increased dyspnea may be aggravated by these drainage angles. In such cases, horizontal positioning or modified drainage angles are often adopted to reduce discomfort and avoid adverse effects while still supporting effective airway clearance.<sup>22</sup>

## PPCs and the Role of ACBT

PPCs are among the most common and clinically significant adverse outcomes following CABG surgery. These complications have a profound effect on the postoperative course by delaying progressive recovery, prolonging the duration of mechanical ventilation, increasing the risk of intensive care unit readmission, and extending hospital length of stay. Collectively, these outcomes place a considerable burden not only on the patient but also on healthcare systems.<sup>19</sup>

The development of PPCs is closely linked to both the general anesthesia administered during surgery and the surgical trauma inflicted during median sternotomy and manipulation of thoracic structures. These factors can result in a cascade of multisystem complications that extend beyond the pulmonary system, affecting multiple organ systems such as the cardiovascular, neurological, pulmonary, musculoskeletal, renal, and integumentary systems. For instance, patients may experience transient or long-term cardiac arrhythmias, postoperative cognitive dysfunction, reduced mobility, renal insufficiency, and delayed wound healing or infections.<sup>19</sup>

From a respiratory standpoint, PPCs encompass a range of pathophysiological changes including reduced chest wall expansion, diminished lung volumes and capacities, atelectasis, and respiratory muscle dysfunction. These impairments

**Table 1** The Component of ACBT

Breathing Cycle	Technique	Purpose
Breathing Control	Tidal volume breathing using a diaphragmatic breathing pattern at the patient's natural rate and volume	Promotes recovery from respiratory muscle fatigue, corrects desaturation, alleviates bronchospasm, and reduces sensations of breathlessness (dyspnea)
Thoracic Expansion Exercises	Three to four slow, deep inhalations through the nose, each followed by an inspiratory hold lasting approximately three seconds	Facilitates collateral ventilation, helping to recruit under-ventilated lung areas and mobilize air behind retained secretions to aid in airway clearance
Forced Expiration Technique	One to two forced expiratory maneuvers (commonly referred to as "huffs"), interspersed with tidal volume breathing	Increases peak expiratory flow, thereby enhancing mucus clearance while minimizing the risk of dynamic airway collapse

predispose patients to further complications such as pleural effusion, hospital-acquired pneumonia, pulmonary embolism, acute respiratory distress syndrome, and phrenic nerve injury. In severe cases, surgical site complications such as thoracic wound infections and mediastinitis may occur, both of which are associated with significantly increased rates of postoperative morbidity and mortality.<sup>15</sup>

The onset and severity of PPCs are influenced by a variety of factors across the perioperative period. These include preoperative factors such as pre-existing pulmonary disease or poor functional capacity, intraoperative elements including the duration of cardiopulmonary bypass and type of surgical access, and postoperative conditions such as pain, immobility, and ineffective cough. Among all causes of postoperative respiratory symptoms, atelectasis remains the most frequently observed and is considered the primary cause of postoperative dyspnea, followed closely by pleural effusion and pneumonia.<sup>15</sup>

The underlying mechanisms contributing to the decline in pulmonary function following CABG are multifactorial and complex. Three key physiological processes are primarily implicated: 1) Systemic inflammatory response, which is initiated by the cardiopulmonary bypass circuit and the surgical trauma itself, leading to widespread endothelial activation and capillary leak; 2) Neutrophil sequestration within the pulmonary capillaries, a process facilitated by the presence of circulating endotoxins, resulting in localized inflammation and impaired gas exchange; and 3) Release of proinflammatory mediators, including cytokines and interleukins, which further aggravate pulmonary vascular permeability and contribute to tissue injury. These inflammatory responses collectively compromise pulmonary function and predispose patients to PPCs.<sup>14</sup>

Chest physiotherapy including ACBT plays a central role in the prevention and management of PPCs, particularly in the intensive care unit setting where patients are vulnerable to secretion retention and impaired ventilation. The primary goals of chest physiotherapy are to enhance airway clearance, promote lung expansion, and support adequate oxygenation during the recovery period. Conventional chest physiotherapy comprises several components, including manual percussion, guided breathing exercises, incentive spirometry (IS), and effective coughing techniques. These modalities are designed to increase lung volumes, optimize ventilation-perfusion matching, accelerate mucus mobilization and expectoration, and alleviate postoperative pain, all of which contribute to a reduced incidence and severity of PPCs and an overall improved recovery trajectory.<sup>15</sup>

## Dosage and Application of ACBT in Post-CABG Patients

Several studies have investigated ACBT protocols in post-CABG patients (Table 2).<sup>14–17</sup> Typical interventions involve 2–3 daily sessions over 2 to 5 consecutive days postoperatively, each comprising the three phases of ACBT. Positions used include sitting, upright sitting with back support, or Fowler's position, sometimes combined with incentive spirometry and other chest physiotherapy modalities.

For example, Savci et al applied ACBT twice daily for 15 minutes on postoperative days one and two, and once on day three, in sitting or semi-recumbent positions, alongside standard postoperative physiotherapy including breathing exercises, coughing instruction, and upper limb mobilization. Jain and Mistry (2018) conducted two daily sessions of 2–3

**Table 2** Dosage of ACBT in Post-CABG Patients

Author, (Year)/Study Design	Patient Characteristics	ACBT Dose and Duration
Savci et al (2006)/Prospective randomized study. <sup>17</sup>	Age >18 years, stable, no chronic pulmonary disease	3 consecutive days; Day 1 and 2: 2×15 minutes; Day 3: 1×15 minutes
Jain & Mistry (2018)/Randomized controlled trial. <sup>16</sup>	Age 30–65 years	3 consecutive days; 2 sessions/day, 2–3 cycles/session
Derakhtanjani et al (2019)/Randomized clinical trial. <sup>14</sup>	Age 18–60 years, non-emergency, stable	2 consecutive days; 1 session/day, 3 cycles/session, 10 minutes/session
Hussain et al (2022)/Single-center, parallel-group randomized controlled trial (RCT). <sup>15</sup>	Age 30–65 years, stable	5 consecutive days; 2 sessions/day, 20 minutes/session

ACBT cycles for three days in upright sitting, combined with IS. Derakhtanjani et al used Fowler's position with slow nasal breathing control, one session per day for two days, including three cycles of ACBT lasting 10 minutes each. Hussain et al provided ACBT twice daily for 20 minutes over five days as an adjunct to conventional chest physiotherapy techniques. Currently, no data explicitly address the safety and adverse effects of ACBT in post-CABG patients, though inclusion criteria across studies generally involved stable hemodynamics and absence of severe comorbidities.<sup>14-17</sup>

## Effects of ACBT on Physiological Parameters and Functional Outcomes

Several studies have investigated the impact of ACBT on postoperative outcomes in patients undergoing CABG surgery.<sup>14-17</sup> Derakhtanjani et al reported that while no significant changes in arterial oxygen partial pressure (PaO<sub>2</sub>) were observed on the first postoperative day following ACBT, a significant increase was evident by the second day. A concurrent significant increase in oxygen saturation (SaO<sub>2</sub>) was also observed on both postoperative days. These findings suggested that ACBT has a delayed but measurable effect on oxygenation. In contrast, conventional chest physiotherapy resulted in earlier PaO<sub>2</sub> improvements. Both interventions were associated with significant increases in heart rate and respiratory rate, reflecting enhanced respiratory drive following therapy.<sup>14</sup>

Jain and Mistry (2018) demonstrated that ACBT combined with IS significantly improved respiratory rate, breath-holding time, and partial pressure of carbon dioxide (PaCO<sub>2</sub>). However, the group receiving conventional chest physiotherapy plus IS showed greater improvements in SpO<sub>2</sub> and PaO<sub>2</sub>. The observed improvements in gas exchange parameters are attributed to the mechanisms of ACBT, which include enhanced collateral ventilation, improved secretion clearance, and optimized breathing control. The TEE promotes alveolar recruitment and collateral airflow, while the FET facilitates mucus mobilization, and BC helps maintain ventilatory stability. IS further augments alveolar expansion and oxygenation by encouraging deep, sustained inspirations.<sup>16</sup>

Savci et al also found that ACBT and IS both resulted in significant improvements in blood gas parameters, including pH, PaO<sub>2</sub>, and SaO<sub>2</sub>, by postoperative day five. ACBT was particularly effective in reducing PaCO<sub>2</sub>, indicating enhanced ventilation. However, both interventions led to mild arterial hypoxemia on day one, highlighting the early postoperative vulnerability of pulmonary function.<sup>17</sup>

Regarding postoperative pain, Derakhtanjani et al observed comparable increases in pain scores (measured by visual analog scale, VAS) in both ACBT and conventional chest physiotherapy groups during the early postoperative period.<sup>14</sup> Conversely, Savci et al reported that the combination of ACBT with IS significantly reduced sternotomy-related pain during deep inspiration, though the difference compared to IS alone was not statistically significant. This suggests that ACBT may have an adjunctive role in pain modulation, likely due to the progressive and patient-controlled nature of breathing exercises.<sup>17</sup>

Hussain et al reported that both ACBT and conventional physiotherapy contributed to a downward trend in dyspnea scores, indicating subjective respiratory improvement. Improvements in pulmonary function were also notable. When combined with conventional physiotherapy, it significantly enhanced FEV<sub>1</sub> and chest expansion over five days of Phase I rehabilitation.<sup>15</sup> Similarly, Savci et al documented significant reductions in FEV<sub>1</sub>, VC, FVC, and PEF on postoperative day five compared to preoperative values in both ACBT and IS groups. Although pulmonary function remained below baseline, the use of ACBT appeared to support gradual recovery and prevent further decline. Radiological findings indicated high rates of early postoperative atelectasis in both groups, which improved by day five without significant between-group differences. Notably, no instances of pneumothorax or pulmonary edema were reported.<sup>17</sup>

Functional capacity, measured by the six-minute walk test, showed only a slight, statistically nonsignificant decline on postoperative day five compared to preoperative levels in the study by Savci et al. Oxygen saturation and heart rate remained stable during the test, and no significant intergroup differences were observed. These findings suggest that ACBT contributes to the preservation of functional capacity during early recovery.<sup>17</sup>

In summary, the physiological and functional improvements observed following ACBT can be explained by its multifaceted mechanisms. TEEs enhance alveolar ventilation and recruit collapsed lung regions; the FET facilitates airway clearance; and BC prevents fatigue and promotes respiratory stability. When combined with IS, these effects are

potentiated, resulting in improved gas exchange, reduced dyspnea, better preservation of pulmonary function, and maintenance of functional capacity in the early postoperative phase of CABG recovery.<sup>14–17</sup>

ACBT yields similar outcomes to conventional physiotherapy techniques in improving postoperative pulmonary function. ACBT and routine chest physiotherapy both significantly improved SaO<sub>2</sub> and reduced PPCs following cardiac surgery. Although techniques like IS and deep breathing exercises have long been employed, ACBT may offer an additional advantage due to its active secretion clearance mechanism. Nevertheless, larger randomized trials are warranted to determine its long-term benefits compared to standard practices.<sup>14</sup>

While the short-term benefits of ACBT are well established, particularly in improving pulmonary function, gas exchange, and secretion clearance in the immediate postoperative period, evidence on its long-term impact remains limited. Several systematic reviews and meta-analyses have shown that interventions such as inspiratory muscle training (IMT), which share components with ACBT, can enhance respiratory muscle strength and reduce the incidence of PPCs following cardiac surgery. However, improvements in functional capacity, peak expiratory flow, and health-related quality of life were inconsistent and often not sustained beyond hospital discharge. These findings highlight a crucial gap in current evidence: while ACBT may offer physiological and symptomatic relief in the short term, further longitudinal studies are needed to determine its effectiveness in enhancing long-term pulmonary recovery, reducing readmission rates, and improving validated quality-of-life outcomes in patients after CABG surgery.<sup>23–25</sup>

Despite its advantages, ACBT requires adequate patient participation, correct instruction, and physical ability to perform each component, especially the FET (huffing) phase. These requirements may limit its feasibility in patients recovering from surgery who experience fatigue or exhibit cognitive impairment. Moreover, there is significant variability in how protocols are applied, and no standardized dose or format exists across clinical settings, complicating implementation. In chronic lung disease, studies highlight the need for appropriate patient selection and adaptation of breathing techniques, principles that should also apply to post-CABG care.<sup>26,27</sup>

While some systematic reviews support the use of airway clearance techniques and inspiratory muscle training in post-cardiac surgery rehabilitation, results remain inconsistent, and no major cardiopulmonary societies have issued formal guidelines endorsing ACBT specifically in this setting.<sup>25–27</sup>

Although current studies provide encouraging results regarding the short-term benefits of ACBT after CABG surgery, the overall evidence remains limited and somewhat inconsistent. For example, Derakhtanjani et al<sup>14</sup> reported no significant difference in arterial blood gas parameters between ACBT and routine physiotherapy, while Savci et al<sup>17</sup> and Jain & Mistry<sup>16</sup> found differing improvements depending on whether ACBT was paired with incentive spirometry or manual chest physiotherapy. Some findings, such as those by Grammatopoulou et al, suggest that ACBT does not significantly outperform conventional methods in reducing pulmonary complications, particularly in populations with thoracic trauma.<sup>12</sup> Moreover, studies by ManiArasi et al and Shingavi et al showed greater benefit of ACBT in abdominal surgery than in cardiac populations, indicating that efficacy may be context-specific.<sup>10,13</sup>

Methodological limitations further reduce the strength of current evidence. Several studies suffer from small sample sizes, short intervention durations (2–5 days), lack of long-term follow-up, and no standardized protocols. Most trials did not measure full pulmonary function parameters or used a limited evaluation, such as chest expansion at a single anatomical level. Additionally, patient comprehension of subjective scales, such as the visual analog scale for pain assessment, was variable, particularly among elderly patients. Oxygen supplementation protocols were also poorly controlled, which may have confounded the observed outcomes.<sup>14,15</sup>

While ACBT is generally safe and well tolerated, both ACBT and conventional chest physiotherapy (manual percussion, IS, early mobilization) were associated with only mild pain and acceptable respiratory responses. However, differences in mechanisms were apparent—ACBT improved ventilation parameters (eg, PaCO<sub>2</sub>, RR, breath holding time), whereas conventional methods better enhanced oxygenation markers (eg, oxygen saturation, PaO<sub>2</sub>).<sup>16</sup> These findings underscore the need for a more nuanced, patient-specific approach in selecting physiotherapy interventions post-CABG, potentially combining modalities to maximize benefits.

Collectively, these studies underscore the necessity of further randomized controlled trials with standardized ACBT protocols, long-term follow-up, and stratified patient analysis to determine which subgroups benefit most. Inclusion of

broader physiological outcomes, patient-reported quality-of-life measures, and cost-effectiveness analyses would also strengthen the clinical applicability of findings in real-world settings.

## Conclusion

The ACBT emerges as an effective and practical respiratory physiotherapy approach to address PPCs following CABG surgery. By promoting airway clearance, improving oxygenation, and enhancing lung function, ACBT contributes significantly to the recovery of postoperative cardiothoracic patients. Its non-invasive, cost-effective, and patient-centered nature makes it a valuable component of postoperative care. Given these advantages, ACBT holds potential to be integrated into standardized physiotherapy protocols following CABG, either as a primary technique or in conjunction with other established modalities such as incentive spirometry and manual chest physiotherapy. Nevertheless, the current evidence base is limited by methodological heterogeneity, short intervention durations, small sample sizes, and lack of long-term follow-up. These limitations highlight the need for further investigation. Future research should prioritize high-quality randomized controlled trials that define optimal treatment frequency and duration, identify patient subgroups most likely to benefit, and assess long-term functional outcomes, quality of life, and cost-effectiveness across diverse healthcare settings.

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