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Effects of positive expiratory pressure and breath stacking training on pulmonary function in cardiac surgery patients: a randomized controlled trial

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KEYWORDS
Positive expiratory pressure;
Breath stacking;
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Pulmonary function.

ABSTRACT
This study aimed to investigate the effects of adding positive expiratory pressure (PEP) and breath stacking (BS) training to routine chest physical therapy after cardiac surgery on pulmonary function (PF), respiratory muscle strength (RMS), and chest wall expansion (CWE) in comparison to receiving routine chest physical therapy alone. Thirty-four cardiac surgery patients were assigned randomly to either the PEP (n=10), BS (n=12), or control group (CON) (n=12). All participants received routine chest physiotherapy. The PEP training consisted of 5 breaths/set, 6 sets/session, 2 sessions/day for three days postoperatively via a BreathMAX device, while the BS training involved 5 breaths/set, 3 sets/session, 2 sessions/day for three days postoperatively. All participants were assessed for PF, RMS, and CWE. Results showed that after training, all groups showed a significant increase in force vital capacity, vital capacity, total lung capacity, and CWE (p-value < 0.01) compared to postoperative day 2. The PEP and CON groups also exhibited a significant increase in peak expiratory flow rate and forced expiratory volume in one second. Moreover, a significant increase in maximal inspiratory pressure and maximal expiratory pressure on postoperative day 5 was observed in the BS and CON groups compared to postoperative day 2. However, no significant differences between the groups were found. The three protocols were equally efficacious concerning PF recovery during the first 5 postoperative days. When compared with routine therapy, BS tended to yield greater RMS. Meanwhile, PEP tended to produce better PF and CWE than the other two techniques. Therefore, physiotherapists should consider post-operative management as a key role in these patients, especially when using the chest physical therapy technique, since this technique has different method and is beneficial for the reduction in post-operative complications.

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Introduction

Cardiac surgery is an effective treatment for patients with coronary heart disease. However, this approach may affect the respiratory function significantly. Pulmonary impairments include postoperative pain from median sternotomy, respiratory muscle dysfunction, lung volume decrease, and impaired mucociliary clearance function[1], which can lead to a prolonged length of hospital stay, higher health care cost, morbidity, and mortality[2]. The cause of pulmonary impairment is multifactorial; the most commonly reported risk factors in the early postoperative period are pain, a limited ability to take a deep breath, and sternal pain[3-6]. In the early post-cardiac surgery period, lung functions, measured in terms of forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1), usually decline by 40% - 50%[3]. Respiratory muscle strength also decreases during the first days after surgery[3].

Chest physiotherapy is an established recommendation to prevent pulmonary impairments in cardiac surgery patients[8,9]. Postoperative treatment includes airway clearance techniques, early mobilization, positioning, and deep breathing exercises[10]. Various mechanical devices have also been used to improve postoperative pulmonary function, e.g., incentive spirometry (IS) and positive expiratory pressure (PEP). IS encourages patients to perform sustained maximal deep breathing through a visual biofeedback mechanism[11]. The PEP device is used in airway clearance therapy to enhance function of the diaphragm and improve atelectasis after surgery[7]. However, the ability of a patient to perform IS and PEP can be impaired by pain, dyspnea, and weakened respiratory muscle function[12]. Therefore, an increasing interest in alternative methods to promote lung expansion without pain has been observed. A newer technique is breath stacking (BS), which can be used in postoperative patients with post-surgery pain to help increase inspiratory volume and maintain inspiration for a long period of time[13-15].

To our knowledge, there have been no studies comparing chest physiotherapy with IS, PEP, and BS in terms of their effects on pulmonary function and respiratory muscle strength in cardiac surgery patients. The aim of this study was, therefore, to evaluate the efficacy of routine physiotherapy plus PEP and routine physiotherapy plus BS in comparison with a control group that received routine physiotherapy plus IS in improving pulmonary function and respiratory muscle strength in patients undergoing heart surgery. Our hypothesis was that a significant difference in pulmonary function and respiratory muscle strength would be found after training program.

Materials and methods

Trial design

This was a single-blinded randomized controlled trial involving cardiac surgery patients, who were randomly allocated into three groups—the positive expiratory pressure (PEP), breath-stacking (BS), and control (CON) groups—before the first visit using block allocation. This study was approved by the Human Research Ethics Committee (HREC), Faculty of Medicine, Prince of Songkla University (No. 56-400-11-2).

Participants

We recruited cardiac surgery patients from Songklanagarind Hospital. The inclusion criteria were surgery via median sternotomy, good ability to communicate, no respiratory disease before surgery that affects the respiratory system, and cardiac surgery performed between September 2013 and December 2015. Meanwhile, the exclusion criteria were intubation for > 48 hours after surgery, need for reintubation for 5 postoperative days, hemodynamic instability (heart rate >120 beats per minute, systolic blood pressure < 90 or >140 mmHg, respiratory rate > 30 breaths per minute, or oxygen saturation < 90.0%), hemodynamic complications (cardiac arrhythmia, mean arterial blood pressure < 70 mmHg, or intraoperative myocardial infraction), re-median sternotomy, and postoperative complications (pneumonia, pulmonary edema, pleural effusion, or pneumothorax). A total of 67 patients were recruited, 31 of whom were excluded due to various reasons; the remaining 36 patients were randomly allocated to the PEP, BS, and CON groups (Figure 1 and Table 1) by an independent investigator. The data related to the patients who died were also excluded from the statistical analysis. All participants received the same routine postoperative chest physical therapy, which included an optimal treatment for pain control. A verbal pain score was obtained via a numeric rating scale (NRS)(16), and physiotherapy was initiated on postoperative day 1 in all cases.

Sample size calculation

Based on the results of Baumgarten MC(17) and an estimation on the basis of IS and BS training measured using FVC and inspiratory volume on postoperative day 5, and assuming a power of 80%, a significance level of 5%, and a dropout rate of 20%, a minimum sample size of 36 was required for this study in order to detect a clinically meaningful difference between groups using FVC and inspiratory volume.

Interventions

Before the operation, the patients received general information about postoperative chest physical therapy routines provided by same physical therapists for all patients. Demographic, functional, and surgical data were recorded. All patients received chest physical therapy once daily as normally performed during the first 5 postoperative days. Therapy consisted of early mobilization and secretion removal, instructions on breathing exercises including breathing control and deep breathing, deep breathing with a device using an incentive spirometer (TRIFLO II™, Sherwood Medical, St. Louis, MO, USA), supported coughing and huffing, daily active limb exercises, chest mobilization with correct posture, and assistance with turning from side to side and sitting (out-of-bed). The patients were mobilized as early as possible by the physical therapists. The patients sat out-of-bed and/or stood on the first postoperative day, walked in the room or a short distance in the ward corridor on postoperative days 1-3, and walked a longer distance in the ward corridor or up and down stairs on postoperative day 4. The patients were randomly allocated into three groups; those in the control (CON) group received only the procedures described above. Meanwhile, the PEP group participants, the physical therapist beside them and while in the supine position with the head of the bed elevated 45°, they were instructed to inspire slowly while expiring slowly and long at functional residual capacity (FRC) in order to open the airway and prevent alveolar collapse with a load of 6 cmH_2O using a BreathMAX device for 5 breaths/set, 6 sets, twice a day, for three days (postoperative days 3-5) and resting for at least two minutes between sets.(18-20). The BS group participants, on top of the procedures of the CON group, practiced inspiratory efforts using a face mask with a unidirectional valve(17). Patients, in the supine position with the head of the bed elevated 45°, were asked to inspire while wearing a mask that was adjusted to allow only inspiration while occluding the expiratory branch. They were asked to perform successive inspiratory efforts for a period of 20 seconds, and then the expiratory branch was opened to allow expiration; the procedure was performed twice a day for three days (postoperative days 3-5), 3 sets of 5 maneuvers/set, with a rest of at least two minutes between sets(15,21). The intervention for all patients were conducted by the same physical therapist.

For safety purposes, their cardiovascular and respiratory parameters were monitored, and the interventions would have been stopped in case hemodynamic instability, i.e., respiratory rate > 30 breaths/min, heart rate > 120 beats/min, or oxygen saturation <90.0%, was detected. However, this eventuality did not occur during the procedures in our trial.

Outcomes

Outcome measurements were carried out both pre- and post-breathing training during the first 5 postoperative days by an independent investigator blinded to the interventions. The patients performed the lung function tests of forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), vital capacity (VC), total lung capacity (TLC), peak expiratory flow rate (PEFR), maximal inspiratory pressure (MIP), maximal expiratory pressure (MEP), and chest wall expansion (CWE).

The lung function tests were performed both before and after breathing training using a portable computerized spirometer (BTL-08 MT Plus ECG, BTL Group Ltd., UK). The measurement procedures followed the standard guideline of ATS/ERS (2005)[22].

Inspiratory and expiratory muscle strength was assessed using maximal inspiratory pressure (Micro RPM, Micro Medical, Inc., Chatham Maritime, Kent, UK) in accordance with the measurement procedures delineated in the standard guideline of ATS/ERS (2002)[23].

Chest wall expansion was measured at the xiphoid process level via a flexible measuring tape (cm) with a control traction force of 1 kg. The patient was seated on the chair and asked to perform three normal breaths, followed by a deep expiration and then a deep inspiration. This was repeated for three times, and the maximum value was recorded.

Statistical analysis

The outcomes of this study were the detected changes in pulmonary functions (FVC, FEV_1, VC, TLC, and PEFR), MIP, MEP, and CWE. The data were cleaned and then imported into the R software version 3.5.2 for analysis. Continuous variables were presented as mean with a standard deviation, and categorical variables were presented as frequency and percentage. The distribution of the variables was checked via the Kolmogorov-Smirnov test. For the comparison between groups, the linear mixed-effects model was employed, meanwhile the Wilcoxon signed-rank test was used for within-the-group comparisons. The statistical significance was set at a *p*-value < 0.05.

Results

Sixty-seven cardiac surgery patients were initially recruited as potential participants in this study. Of those, 31 were excluded:12 patients were intubated for > 48 hours, five had cardiac arrhythmia, four had pleural effusion, three had pulmonary edema, three had pneumonia, two underwent re-median sternotomy, and two patients experienced sudden cardiac arrest. The remaining patients were divided into three groups of 12 patients each. Two patients in the PEP group were lost to follow-up due to cardiac arrhythmia; therefore, 34 patients completed the study. A flow diagram detailing this study's participant inclusion/exclusion is shown in figure 1.

The mean patient age was 56.2 ± 16.0 years in the PEP group, 56.5 ± 13.1 years in the BS group, and 52.8 ± 10.6 years in the CON group. The average body mass index (BMI) was 22.9 ± 4.6 kg/m^2 in the PEP group, 23.7 ±3.1 kg/m^2 in the BS group, and 22.9 ± 4.1 kg/m^2 in the CON group.

The weight, height, systolic blood pressure, heart rate (HR), pulmonary functions (FVC, FEV_1, VC, TLC, and PEFR), MIP, MEP, and CWE were not significantly different among the groups, except for diastolic blood pressure (Table 1).

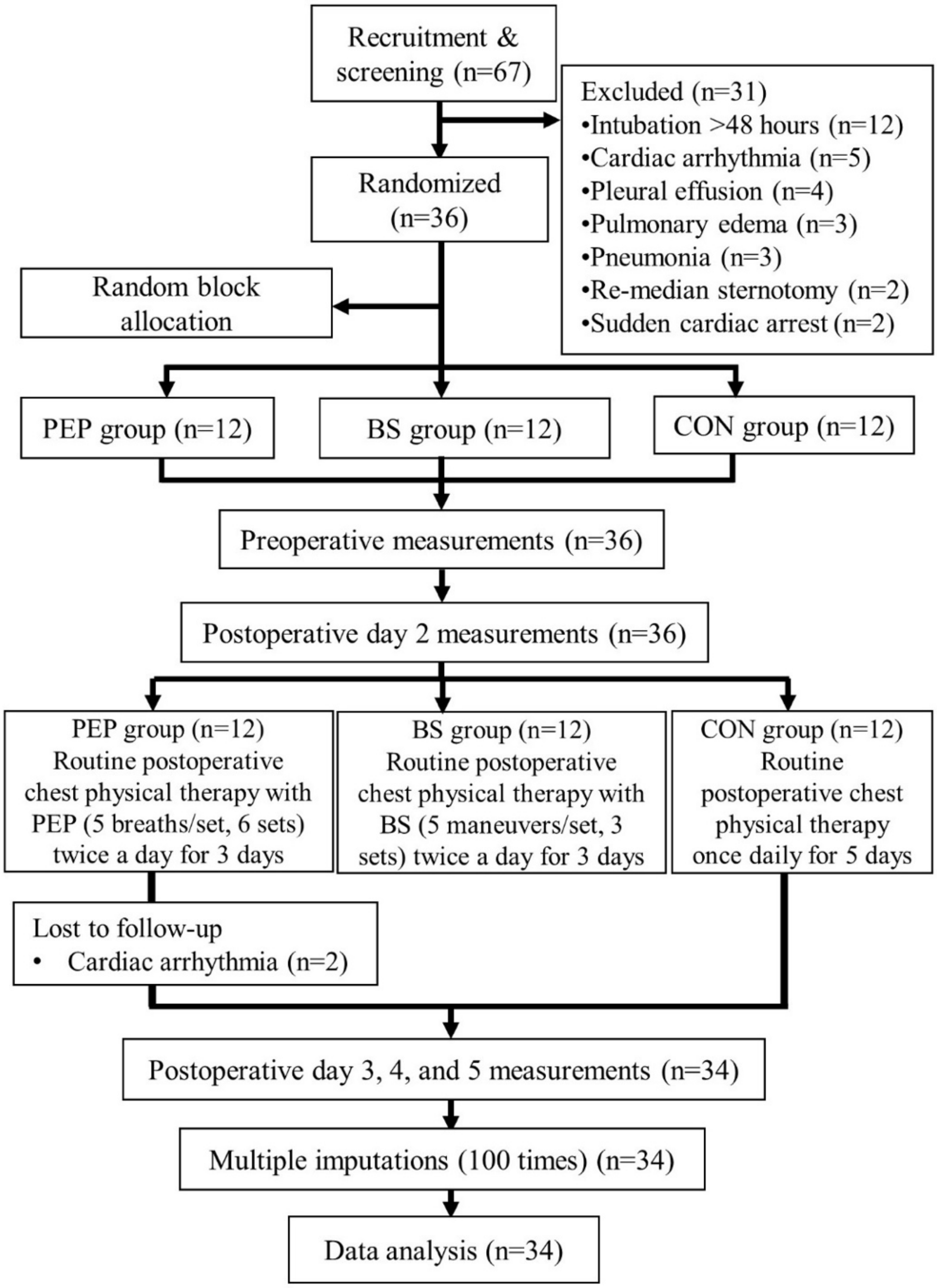

Figure 1 Flow of participants thorough the study. PEP, Positive expiratory pressure; BS, breath stacking training; CON, control.

Table 1 Demographic characteristics of participants (n = 34)

Characteristic	PEP (n = 10)	BS (n = 12)	CON (n = 12)	*p*-value
Age (years), mean (± SD)	56.216.0))	56.5 (13.1)	52.8 (10.6)	0.75
Sex, n (%)				
Male	6.060.0))	7.0 (58.3)	6.0(50.0)	
Female	4.0 (40.0)	5.0 (41.7)	6.0 (50.0)	
Functional class: n (%)				
1	1.0 (10.0)	4.0 (33.3)	3.0 (25.0)	
2	6.0 (60.0)	3.0 (25.0)	5.0 (41.7)	
3	2.0 (20.0)	4.0 (33.3)	4.0 (33.3)	
4	1.0 (10.0)	1.0 (8.4)	0.0 (0.0)	
Type of surgery: n (%)				
CABG	3 (30.0)	5 (41.7)	4 (33.3)	
Valve replacement	5 (50.0)	3 (25.0)	4 (33.3)	
ASD closure	2 (20.0)	4 (33.3)	3 (25.0)	
VSD closure	0 (0.0)	0 (0.0)	1 (8.3)	
Intubation time during surgery (hr), mean (± SD)	4.4 (1.1)	4 (0.9)	4.3 (0.9)	0.95
Weight (kg), mean (± SD)	58.2 (10.3)	61.5 (12.4)	58.99 (12.5)	0.78
Height (cm), mean (± SD)	159.8 (9.0)	160.6 (9.3)	160.3 (8.9)	0.98
BMI (kg/m^2), mean (± SD)	22.9 (4.6)	23.7 (3.1)	22.9 (4.1)	0.85
Systolic BP (mmHg), mean (± SD)	118.516.4))	116.8 (14.1)	118.3 (11.6)	0.95
Diastolic BP (mmHg), mean (± SD)	75.4 (10.1)	66.8 (6.1)	74.8 (8.1)	0.03*
HR (bpm), mean (± SD)	67.0 (12.0)	72.9 (9.7)	76.2 (10.5)	0.15
FVC (L), mean (± SD)	1.8 (0.8)	2.1 (0.8)	2.5 (1.3)	0.23
FEV_1 (L), mean (± SD)	1.3 (0.4)	1.6 (0.7)	2.1 (1.1)	0.07
VC (L), mean (± SD)	1.9 (0.7)	2.4 (0.7)	2.8 (1.0)	0.07
TLC (L), mean (± SD)	3.2 (0.6)	3.2 (1.3)	3.2 (1.3)	1.00

Table 1 Demographic characteristics of participants (n = 34) (cont.)

Characteristic	**PEP (n = 10)**	**BS (n = 12)**	**CON (n = 12)**	***p*-value**
PEFR (L/min), mean (± SD)	2.9 (1.8)	3.5 (2.0)	4.4 (2.2)	0.24
MIP (cmH_2O), mean (± SD)	53.3 (23.6)	65.0 (27.6)	71.8 (40.5)	0.43
Relative MIP (cmH_2O)/Body weight (kg), mean (± SD)	0.9 (0.3)	1.0 (0.4)	1.2 (0.6)	0.27
MEP (cmH_2O), mean (± SD)	56.2 (35.2)	70.4 (32.2)	86.2 (55.3)	0.27
Relative MEP (cmH_2O)/Body weight (kg), mean (± SD)	0.9 (0.6)	1.1 (0.4)	1.5 (1.0)	0.23
CWE (cm), mean (± SD)	3.2 (1.4)	4.2 (1.9)	3.9 (1.94)	0.44

Note: Values are means ± SD n = 34 (15 females, 19 males). CABG, coronary artery bypass graft; ASD, Atrial Septal Defect; VSD, Ventricular septal defect; BMI, Body mass index; Systolic BP, Systolic blood pressure; Diastolic BP, Diastolic blood pressure; HR, Heart rate; FVC, Forced vital capacity; FEV_1, Forced expiratory volume in 1 second; VC, Vital capacity; TLC, Total lung capacity; PEFR, Peak expiratory flow rate; MIP, Maximal inspiratory pressure; MEP, Maximal expiratory pressure; CWE, Chest wall expansion; PEP, Positive expiratory pressure; BS, Breath stacking; CON, Control; kg, Kilogram; cm, Centimeter; kg/m^2, Kilograms per meter squared; mmHg, millimeters of mercury; bpm, Beats per minute; L, liter; L/min, Liters per minute; cmH_2O, Centimeters of water; * p-value < 0.05 (indicative of significant difference between groups).

All pulmonary function and CWE parameters on postoperative day 2 were significantly decreased in every group (p-value < 0.01) compared to preoperative values. After training, on postoperative day 5, a significant improvement in both FVC and VC was observed in all groups (p-value < 0.01); the same was true for TLC (p-value < 0.05 overall; p-value < 0.01 for PEP, BS, and CON groups). After training, CWE improved significantly in all groups (p-value < 0.05 for BS, and < 0.01 for PEP and CON groups, respectively) compared to the postoperative day 2 values (Figure 2).

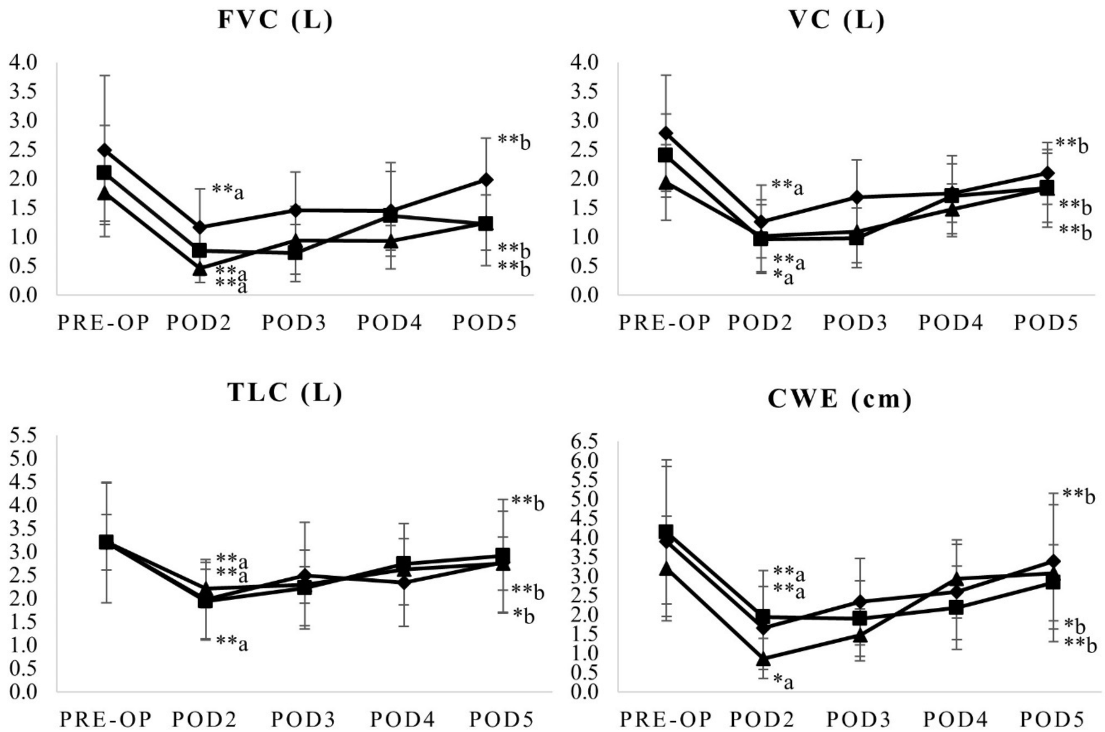

Figure 2 Mean of FVC, VC, TLC, and CWE values before surgery and on postoperative days 2, 3, 4, and 5 following cardiac surgery. Values are means ± SD n = 34 (15 females, 19 males). PRE-OP, Preoperatively; POD2, postoperative day 2; POD3, postoperative day 3; POD4, postoperative day 4; POD5, postoperative day 5; FVC, forced vital capacity; VC, vital capacity; TLC, total lung capacity; CWE, chest wall expansion; L, liter; cm, centimeter; [*a]p-value (preoperatively-postoperative day 2) < 0.05; [**a]p-value (preoperatively-postoperative day 2) <0.01; [*b]p-value (postoperative days 2-5) < 0.05; [**b]p-value (postoperative days 2-5) <0.01; control group = diamond symbols; breath stacking group = square symbols; positive expiratory pressure group = triangle symbols.

Meanwhile, a significant improvement in PEFR and FEV_1 was seen only in the PEP and CON groups (p-value < 0.05 and < 0.01, respectively) compared to postoperative day 2. However, there was no statistically significant difference between the three groups. Respiratory muscle strength values are given in figure 3. On postoperative day 2, a significant decrease in MIP was found in the BS group (p-value < 0.01), while MEP decreased significantly in the BS and CON groups (p-value < 0.01) compared to preoperative values. After training, on postoperative day 5, MIP and MEP improved significantly in the BS and CON groups (p-value < 0.05) (Figure 3).

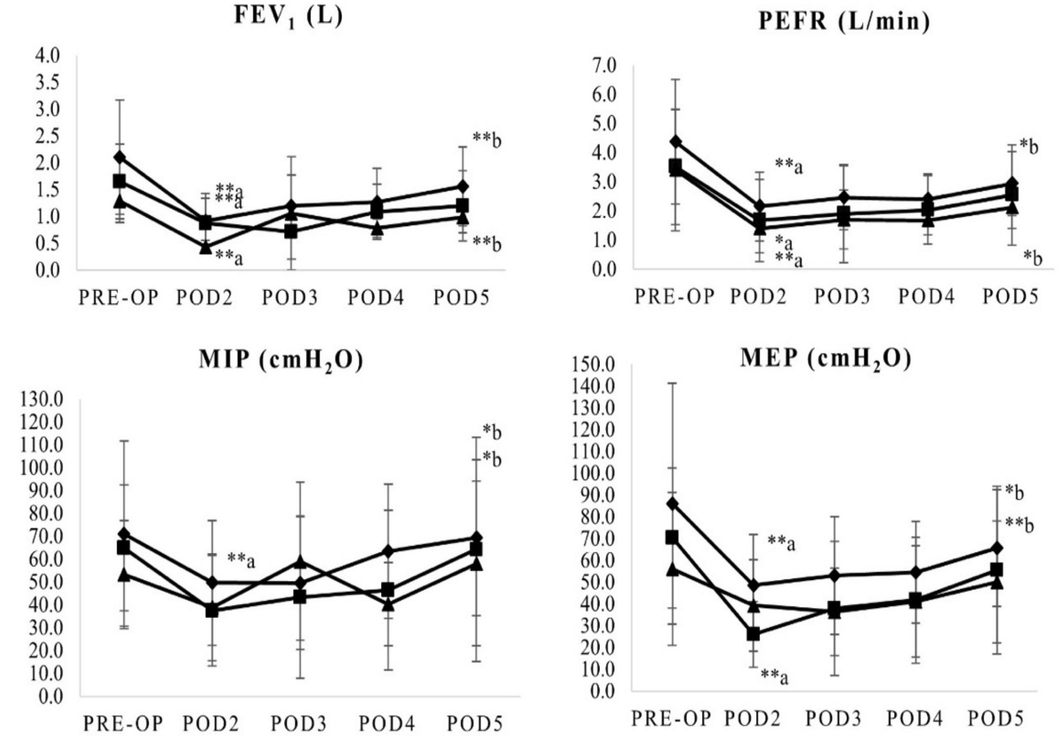

Figure 3 Mean of FEV_1, PEFR, MIP and MEP values preoperatively and on postoperative days 2, 3, 4, and 5 following cardiac surgery. Values are means ± SD n = 34 (15 females, 19 males). PRE-OP, preoperatively; POD2, postoperative day 2; POD3, postoperative day 3; POD4, postoperative day 4; POD5, postoperative day 5; FEV_1, forced expiratory volume in 1 second; PEFR, peak expiratory flow rate; L, liter, L/min, liters per minute; MIP, maximal inspiratory pressure; MEP, maximal expiratory pressure; cmH_2Ocentimeters of water; [*a]*p*-value (preoperatively-postoperative day 2) < 0.05; [**a]*p*-value (preoperatively-postoperative day 2) < 0.01; [*b]*p*-value (postoperative days 2-5) < 0.05; [**b]*p*-value (postoperative days 2-5) <0.01; control group = diamond symbols; breath stacking group = square symbols; positive expiratory pressure group = triangle symbols.

It was also found that pain on the 2[nd] postoperative day was significantly higher in the three groups (*p*-value < 0.01) compared to preoperative values. However, the reported pain scores on postoperative day 5 were significantly lower in the CON and BS groups (*p*-value < 0.01 and < 0.05, respectively) compared to the 2[nd] postoperative day values; there was no statistically meaningful difference between the groups (Table 2).

Table 2 Pain data before surgery and on postoperative days 2, 3, 4, and 5 following cardiac surgery (mean ± SD)

Variable	Group	PRE-OP	POD2	POD3	POD4	POD5	% of mean difference
	PEP	0.0 (0.0)	4.7 (1.6) **a	2.4 (2.3)	3.5 (2.1)	2.0 (2.7)	-57.5
NRS	BS	0.0 (0.0)	4.1 (2.6) **a	4.0 (2.4)	3.7 (2.7)	2.0 (1.9)*b	-51.2
	CON	0.0 (0.0)	3.9 (1.7) **a	3.5 (2.4)	2.8 (1.6)	1.1 (1.0)**b	-71.8

Note: Values are means ± SD n = 34 (15 females, 19 males). PRE-OP, Preoperatively; POD2, Postoperative day 2; POD3, Postoperative day 3; POD4, Postoperative day 4; POD5, Postoperative day 5; NRS, Numeric rating scale; PEP, Positive expiratory pressure; BS, Breath stacking; CON, Control; **a*p*-value (preoperatively-postoperative day 2) < 0.01; *b*p*-value (postoperative days 2-5) < 0.05, **b*p*-value (postoperative days 2-5) < 0.01.

Discussion

The aim of this study was to compare the effectiveness of PEP and BS added to the routine chest physical therapy with that of the routine chest physical therapy alone on pulmonary function, respiratory muscle strength, and CWE in cardiac surgery patients. It was found that, on the 5th postoperative day, pulmonary function deteriorated severely in all groups (between 60% and 75% of the preoperative values). The reduction found in our study is consistent with those reported by several previous studies[3,21,24]. The drop in expiratory flow rates, respiratory muscle strength, and CWE impairs both the cough mechanism and the secretion clearance function and the postoperative pain reduces one's ability to cough. In this study, the NRS on the 5th postoperative day was similar in all groups. There is some evidence that regular chest physiotherapy significantly decreases the incidence of pulmonary complications after cardiac surgery[25,26].

In our study, all groups demonstrated a significant improvement in FVC, VC, TLC, and CWE after three days of training. This was consistent with findings from the previous studies, which have indicated an improvement in pulmonary function after routine chest physical therapy with PEP[18] and BS[15] among cardiac surgery patients. A significant decrease in pulmonary function, persisting up to four months after cardiac surgery, has been previously reported[27]. Therefore, the results of the present study support the hypothesis that chest physical therapy facilitates the recovery of pulmonary functions within one week after cardiac surgery, which may lead to a reduction in the incidence of respiratory complications and a shorter length of hospital stay[28].

The patients who participated in the PEP group exhibited a better recovery in terms of both PEFR and FEV_1 on postoperative day 5. This indicates the clinical importance of PEP, which encourages patients to perform forced expiration through water resistance and prolong the expiratory time, resulting in decreased respiratory rate, increased lung volume, and better expiratory flow rate[29]. The results of our study are consistent with those of Borghi-Silva et al. (2005) who reported a better recovery of pulmonary functions in the group that received deep breathing training via PEP and early mobilization compared to those receiving deep breathing training without PEP and early mobilization[30]. They concluded that the use of PEP was more effective in restoring pulmonary function[30]. This is similar to the findings of the Westerdahl et al. (2005) study, which reported that coronary artery bypass graft (CABG) surgery patients, who performed exercises using PEP, experienced smaller atelectatic improvements and less reduction in FEV_1 and FVC on postoperative day 4 compared to control group participants, who performed no exercises[18].

Respiratory muscle dysfunction after cardiac surgery may lead to alveolar hypoventilation due to a reduction in pulmonary functions such as tidal volume, vital capacity, and total lung capacity. In the present study, a significant reduction in both MIP and MEP was observed in the BS group on the 2nd postoperative day. Moreover, we found an improvement in respiratory muscle strength among CON and BS group participants on postoperative day 5 (28.2% for MIP and 25.9% for MEP, and 39.5% for MIP and 48.0% for MEP, respectively). A recent study has shown that BS training is associated with a significant recovery of respiratory muscle strength, and that this recovery is directly related to improvement in pulmonary function. Thus, it can be concluded that the use of BS stimulates the maximum sustained inspiration volume[15], which is associated with improved collateral ventilation, lung re-expansion, and stretching of the intercostal muscles to their optimum length; this leads to an effective restoration of respiratory muscle function as demonstrated by the increases in MIP and MEP values. The results of our study are consistent for clinically significant changes in the MIP and MEP, which is usually more than 60 cm H_2O and associated with a improve ability to cough and secretions clearance.

The present study, however, has the limitations including a relatively small sample size and the specificity of its study population. Therefore, our results cannot be extrapolated to other surgical populations. Further studies are needed to investigate the effectiveness of PEP and BS in relation to clinically relevant outcomes such as the prevention of pulmonary complications (atelectasis and pneumonia) and their impact on the length of hospital stay. Future study should be directed toward confirming our findings and expanding this area of research.

Conclusion

This randomized controlled trial demonstrated that the addition of 5 days of PEP and BS training postoperatively to routine chest physiotherapy resulted in a faster recovery of pulmonary function, respiratory muscle strength, and CWE. However, we found no major differences between the three study groups on the 5th postoperative day. A relative increase in pulmonary function and CWE tended to be associated with PEP, while BS training tended to increase respiratory muscle strength more than the other techniques.

Take home messages

The present study demonstrated that the addition of PEP and BS training to routine chest physiotherapy. A relative increase in pulmonary function and CWE associated with PEP, while BS training tended to increase respiratory muscle strength. However, no major differences between the three study groups. Therefore, physiotherapists should consider post-operative management as a key role in these patients, especially when using the chest physical therapy technique, since this technique has different method and is beneficial for the reduction in post-operative complications.

Conflicts of interest

The authors declare no conflict of interest.

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