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Research article

Contrasting effects of three breathing techniques on pulmonary function, functional capacity and daily life functional tasks in patients following valve replacement surgery- A pilot randomized clinical trial

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RESEARCH HIGHLIGHTS

- The present pilot randomized clinical trial is the first of a kind that exhibits the effects of three breathing exercises in patients following valve replacement cardiac surgery.
- The study demonstrates the individual and contrasting effects of volume spirometry, volume spirometry and deep breathing exercise between preoperative day until postoperative day 7 in terms of pulmonary function and function activities.

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ABSTRACT

Background: Valve replacement surgeries affect the physiological mechanisms of patients leading to various postoperative pulmonary complications. Lung expansion therapy consisting of numerous techniques is routinely used for the prevention and treatment of these complications.
Objectives: Our study aimed to compare the effects of diaphragmatic breathing (DB), flow (FS) and volume-oriented incentive spirometer (VS) in patients following valve replacement surgery.
Methods: 29 patients posted valve replacement surgeries were randomly assigned to VS, FS and DB groups. Patients underwent preoperative training and seven-day rehabilitation post-surgery. Pulmonary function tests were performed before surgery and for seven days afterward. On the seventh postoperative day, patients performed a six-minute walk test and completed a functional difficulties questionnaire (FDQ).
Results: Pulmonary function test values reduced in all three groups postoperatively when compared to the preoperative values but improved by the seventh postoperative day ($p < 0.05$). On comparing the seventh postoperative day values to the preoperative values, the VS group had no significant difference ($p = 1.00$) (Forced Vital Capacity- % change: DB-37.76, VS-1.59, FS-27.98), indicating that the value had nearly returned to the baseline. As compared to the DB and FS groups, FVC showed a greater improvement in the VS group ($p = 0.01$ and $p = 0.06$ respectively). No significant differences were observed between groups for distance walked ($p > 0.05$), however, FDQ scores demonstrated positive changes in favor of VS when contrasted with FS or DB ($p < 0.05$).
Conclusion: Diaphragmatic breathing, flow or volume-oriented spirometer could improve pulmonary function in the postoperative period. The volume-oriented spirometer, however, was found to be the most beneficial among the three techniques in improving patients' pulmonary function and daily life functional tasks. Further research is warranted to confirm these findings.

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1. Introduction

Cardiac surgeries include surgical procedures for pathologies of the heart- like ischemic heart disease, valve regurgitation or stenosis- that changes the normal physiology of patients in various ways [1, 2, 3, 4]. These include variations in the cardiac output, systemic vascular resistance, perfusion and oxygenation of tissues, increased inflammation, oxidative stress and hemolysis [2, 3, 4]. In addition, hypothermia, haemodilution, accumulation of interstitial fluid, and depression of immune system is caused due to the use of cardiopulmonary bypass machine [5]. These changes can lead to cardiovascular, pulmonary, renal and cognitive complications [2, 3, 4, 5].

Pulmonary complications are the leading cause of morbidity in patients who undergo these surgeries [6]. Three main factors determine the level of these complications: general health status of the patients, surgical trauma and effects of anaesthesia [7]. Factors like smoking and diabetes are also factors that can contribute to these complications [8]. Pulmonary parameters may be affected by anaesthetics, chest wall changes, and direct lung manipulation. Anaesthesia can reduce functional residual capacity (FRC) by up to 20 %, and thoracic manipulation and rib cage mechanics with a median sternotomy procedure can result in reductions in forced vital capacity (FVC) and forced expiratory volume in the first second (FEV_1) [6,9].

Common pulmonary complications of cardiac surgery include atelectasis, pneumonia, pleural effusion, pneumothorax, pulmonary edema [6]. Intraoperatively, induction of anaesthesia, manual compression of the lungs for surgical exposure and apnea during cardiopulmonary bypass may all cause atelectasis, whereas postoperatively, ineffective cough, low inspiratory attempts, interstitial edema, and immobility may contribute to the deterioration of respiratory function and prolong hospitalization [9]. The postoperative pain and apprehension associated with the cardiac surgery could lead to difficulty in performing deep inspiration and also to cough effectively [10]. This eventually leads to the accumulation of secretions and alters the normal mechanism of gas exchange [11].

Respiratory physiotherapy is usually prescribed for preventing and treating these postoperative pulmonary complications. Its purpose is to enhance ventilation-perfusion matching, improve lung volumes and airway clearance [7, 12]. It consists of different airway clearance techniques, lung expansion therapy, early mobilization and positioning [7].

Lung expansion therapy consists of breathing techniques like diaphragmatic breathing, segmental breathing, ventilatory movement strategy, proprioceptive neuromuscular facilitation techniques for respiration, and using devices like incentive spirometry, positioning and early mobilization [13, 14]. Diaphragmatic breathing facilitates outward motion of the abdominal wall and decreases upper rib cage movement during inspiration and can be used to increase oxygenation and prevent atelectasis. It decreases accessory muscle use and increases diaphragmatic excursion [15, 16]. Incentive Spirometry (IS) is a mechanical breathing device that gives positive feedback and enables the patient to perform slow, long and deep breaths mimicking a natural sigh. This device is available in two types: volume-oriented and flow-oriented spirometers. A flow-oriented incentive spirometer comprises a set of three compartments in a series, each consisting of a ball. A volume-oriented incentive spirometer has a capacity of 4000ml and a one-way valve that prevents exhalation into the device [17].

Various studies have shown an important physiological difference in the effects of the volume and flow-oriented incentive spirometers [18, 19, 20, 21]. When administered, a flow-oriented device leads to labored breathing and increases the thoracic muscle activity whereas a volume-oriented spirometer imposes reduced breathing efforts and also improves the movement of the diaphragm [18, 19].

Cardiac surgeries also affect the functional capacity, thoracic mobility and pulmonary function which taking together could influence the quality of life of these patients [22, 23]. The evaluation of the effectiveness of physiotherapeutic methods in the postoperative period of valve surgery can assist in the choice and recommendation, considering lung function, functional capacity and its impact on the quality of life of these patients. Functional capacity can be assessed using a 6-minute walk test [24]. However, for assessing the limitation experienced in performing activities due to difficulty in thoracic cage movements in cardiac patients, a functional difficulties scale consisting of 13 activities involving the movement at the thoracic regions can be considered [25].

Thus, different techniques in physiotherapy can be used to reduce or prevent postoperative pulmonary complications and improve functional capacity in cardiac surgery patients. Studies have been done to find the effect of these techniques in cardiopulmonary bypass graft surgeries [26, 27]. However, to our knowledge; no studies were found in the case of open valve replacement surgeries. Therefore, this study aimed to compare the effects of diaphragmatic breathing, flow and volume incentive spirometers and on pulmonary function test values, functional capacity (6-minute walk test) and daily life functional tasks (functional difficulty questionnaire) in patients following valve replacement surgeries. Understanding the effects of these techniques could aid in treatment planning for these patients.

2. Materials and methods

2.1. Ethical considerations and registration of the study protocol

This pilot study was conducted in Kasturba Medical College, Mangalore from December 2018 to January 2020 after approval from the Institutional Ethics Committee (IEC KMC MLR 11-17/237). The first half of the study was conducted on Coronary Artery Bypass Graft surgery patients as published in the article by Amin R. et al [26] (Clinical Trial Registry of India by Amin. et al. CTRI/2018/01/011324). Reference number (REF/2018/01/016739)link (http://ctri.nic.in/Clinicaltrials/rmaindet.php?trialid=22202&EncHid=46114.87480&modid=1&compid=19). Our present study is the second half of the same study protocol which is conducted on valve replacement cardiac surgery patients.

2.2. Subjects of this study, randomization and allocation

Eligible participants were selected based on the eligibility criteria. Patients of both genders belonging to the age group of eighteen to eighty years and scheduled for open valve replacement surgery by the cardiac surgeon were included. Patients with hemodynamic instability (systolic pressure <100 mmHg, diastolic pressure <60 mmHg and mean arterial pressure <80 mmHg), those on invasive or non-invasive mechanical ventilation for a period exceeding 24 h post-surgery, patients who are cognitively impaired, unable to understand the method of using the device or uncooperative, patients having vital capacity <10 mL/kg, those having a history of any pulmonary conditions or had undergone major cardiac, pulmonary or abdominal surgery in the last three months were all excluded. All the patients meeting the study criteria were provided with a participant information sheet. Informed consent was duly signed by those willing to participate in the study.

Using block randomization, patients were divided into three groups: flow-oriented incentive spirometer group, volume-oriented incentive spirometer group and diaphragmatic breathing group. Computer-generated random numbered table was used for sequencing. The patients were divided into 5 blocks with 6 patients in each group. A sealed opaque envelope was used to conceal group information and was revealed to the patients only after recruitment into the treatment group. The allocation of groups was concealed from all the investigators except one of them who assigned the patients to groups. Our study followed the CONSORT guidelines [28].

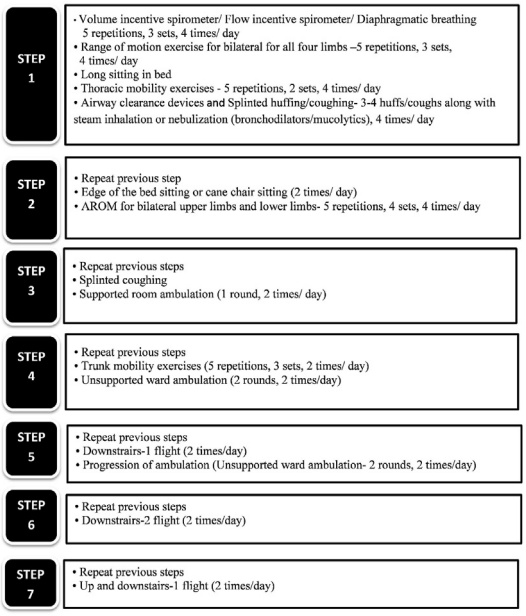

Figure 1. Stepwise protocol for phase 1 cardiac rehabilitation (as adapted from a study conducted by Amin et al. [21]).

2.3. Physical therapy intervention protocols

After being allotted into groups, the patients in all three groups were visited one day before the surgery. Demographic data- such as age, height, weight, body mass index (BMI), smoking, comorbidities-was collected. Preoperative information was given and lung expansion techniques were taught to patients, based on their respective groups, by one of the investigators who was a physiotherapist. Airway clearance techniques (positive expiratory pressure devices, huffing, coughing), range of motion exercises for all four limbs, mobilization (edge of bed sitting, chair sitting, walking, stair climbing) were also taught. Post-surgery, a cardiac rehabilitation protocol was administered to the patients for 7 days under the supervision of the same investigator who performed the preoperative training. Lung expansion techniques based on the respective group (viz. FS, VS, DB), airway clearance techniques and range of motion exercises for all the four limbs were performed four times a day whereas mobilization was performed twice a day. Each session lasted for 30–35 min. The rehabilitation protocol is mentioned in Figure 1. Patients were instructed to continue the same exercises (lung expansion techniques as per the group allocation along with the airway clearance techniques) every two hours under the supervision of the caretaker. A logbook was provided to the caretaker to maintain the records of the exercises performed [26].

2.3.1. Procedure for flow-oriented incentive spirometry (FS) and volume-oriented incentive spirometry (VS)

The patients were positioned in the half-lying position (45°) with a pillow under the knees or in the upright position. They were also instructed to hold the flow spirometer device (Triflow®) upright and perform slow, deep inhalation, holding the ball for a minimum of three seconds, avoiding any forceful expiration. The procedure was performed after the demonstration. The same method was followed for performing volume-oriented incentive spirometry (Coach 2 device®). Instead of the ball, the patients were asked to inhale to raise the piston or plate in the chamber to the set target [26, 29]. The methods of performing FS and VS have been shown in Figures 2A and 2B. Patients in both groups were asked to perform 3 sets of 5 repeated deep breaths every hour they were awake. The therapist supervised the exercise four times a day and the patients were instructed to perform the same for the other times of the day [26].

2.3.2. Procedure for diaphragmatic breathing exercise (DB)

The patients were positioned in a half-lying position (head and back were completely supported and the abdominal wall was relaxed). The patients placed their hands just below the anterior costal margin, on the rectus abdominus muscle and inhaled slowly through the nose, from the functional residual capacity to total lung capacity with a three-second inspiratory hold. Exhalation was performed slowly through the mouth. They were instructed to relax the shoulders and upper chest so that they could feel the rise and fall of the abdomen using the hands placed on it [16, 26]. The method of performing DB is shown in Figure 2C. They were to perform 3 sets of 5 deep breaths every waking hour with the therapist administering it four times a day. The patients were asked to breathe normally, in between the sets of the diaphragmatic breathing exercise [26].

2.4. Measurements

An investigator, who was blinded to the intervention groups assigned to the patients, assessed the outcome measures. Pulmonary function test was the primary outcome measure. Six-minute walk test and functional difficulties questionnaire were secondary outcome measures [26].

2.4.1. Pulmonary function test

Forced vital capacity (FVC), forced expiratory volume in the first second (FEV_1), peak expiratory flow rate (PEFR) were measured by

Figure 2. Methods of performing: A) flow-oriented incentive spirometry, B) volume-oriented incentive spirometry and C) diaphragmatic breathing exercise.

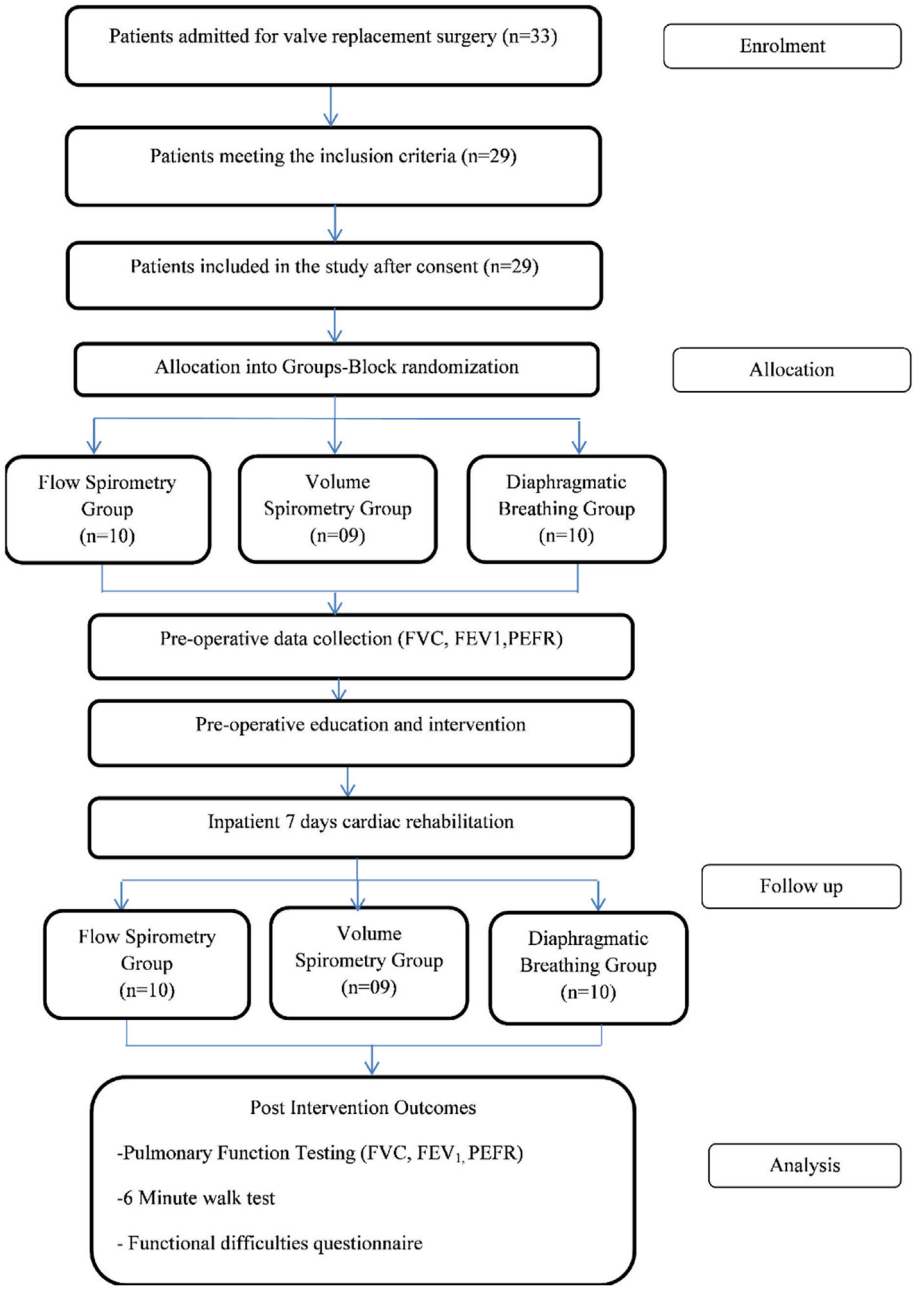

Figure 3. Consort Flow Diagram for the study.

pulmonary function testing (PFT) using EasyOne Plus Portable Diagnostic Spirometer Machine. The procedures were performed according to the American Thoracic Society/European Respiratory Society guidelines [30]. Out of the three trials, the best and reproducible value was considered. These variables were measured on the day before surgery and the first to seventh postoperative days, for all the groups.

2.4.2. Six-minute walk test

The patients performed a 6-minute walk test (6MWT), according to the American Thoracic Society's guidelines on the seventh postoperative day [24]. Heart rate (HR), respiratory rate (RR), peripheral oxygen saturation (SpO_2), dyspnoea and fatigue were measured at the starting and immediately after finishing the test. Modified Borg scale was used to measure dyspnoea and fatigue [31]. Distance covered in meters after 6 min was the main outcome of the test.

2.4.3. Functional difficulties questionnaire

The functional difficulties questionnaire (FDQ) questionnaire was also given to patients on the seventh postoperative day [25]. It is a paper-based questionnaire that comprises thirteen different daily life functional tasks that involve movements associated with the thoracic region. It includes upright sitting, walking with arms swinging freely, coughing/sneezing, rolling over in bed, getting out of bed, washing hair, scratching the back, picking up an object off the ground, turning to reach backward, doing the clasp of a bra or tucking in a shirt at the back of pants, putting on a dressing gown/cardigan/jacket, drying the back with a towel, and pushing a set of drawers shut. The participants graded these different tasks on a 10-cm visual analog scale (VAS) with endpoints 'maximum difficulty' and 'no difficulty'. According to a standardized administration procedure, one of the investigators was present to help in case of any queries while filling the questionnaire. In case of patients'

Table 1. Demographic data of patients who underwent valve replacement surgery.

Variables		FS Group (n = 10)	VS Group (n = 9)	DB Group (n = 10)	p value
Age, years		63.3 ± 9.5	62.3 ± 16.0	53.5 ± 9.0	0.147
Gender (Male: Female)		7:3	7:2	9:1	-
Height (cm)		155.7 ± 7.7	154.8 ± 7.3	157.8 ± 5.5	0.625
Weight (kg)		69.2 ± 12.4	70.8 ± 10.5	79.2 ± 8.9	0.106
BMI		28.3 ± 2.9	29.4 ± 3.3	31.7 ± 3.1	0.062
Co-morbidities	Diabetes (n)	5	6	6	0.77
	Hypertension (n)	6	4	3	0.43
Smoking	Smokers (n)	5	5	6	0.91
	Active smokers (1–5 years:5–10 years) (n)	0:1	1:1	2:1	-
	Quit smoking (1–5 years:5–10 years) (n)	3:1	2:1	3:0	-
Type of Surgery	MVR	6	7	8	0.58
	AVR	2	1	2	0.85
	DVR (AVR + MVR)	1	-	-	0.40
	MVR + CABG	1	1	-	0.59
Duration of surgery (h)		1.8 ± 0.7	1.9 ± 0.6	1.6 ± 0.2	0.629
Baseline PFT variables (Pre op)	FVC	1.59 ± 0.50	1.61 ± 0.41	1.51 ± 0.45	0.87
	FEV_1	1.48 ± 0.63	1.26 ± 0.64	1.47 ± 0.63	0.69
	PEFR	2.55 ± 1.01	2.28 ± 1.03	2.56 ± 1.08	0.81

Values are mean ± SD; n, number; VS, Volume-oriented spirometer DB, Diaphragmatic breathing; BMI, Body mass index; AVR, Atrial valve replacement; MVR, Mitral valve replacement; DVR, Double valve replacement; CABG, Coronary artery bypass grafting; PFT, Pulmonary function test; FVC, Forced vital capacity; FEV_1, Forced expiratory volume in 1 s; PEFR, Peak expiratory flow rate.

inability to complete any task, it was automatically graded as 10 to reflect maximum difficulty. Individual VAS scores, measured to the nearest millimeter, were aggregated for a potential number out of 130. Higher scores indicated greater functional difficulty in performing tasks [25]. The CONSORT flow diagram for this study is mentioned in Figure 3.

2.5. Data analysis

Data was analyzed using IBM SPSS package version 25.0. Armonk, NY: IBM corp. Within-group analysis was done using repeated measures ANOVA and post hoc analysis (Bonferroni's *t*-test). Between groups differences were compared using ANOVA. A p value of less than 0.05 was considered statistically significant.

3. Results

Twenty-nine patients who underwent valve replacement surgeries were included in the study and were divided into three groups. DB and FS group consisted of ten patients each and the VS group had 9 patients. There were no dropouts in the study. None of the patients had any serious adverse events during the intervention or measurement of outcomes. Characteristics of patients such as age, height, weight, BMI, smoking, comorbidities, type and duration of surgery are shown in Table 1. Most of the patients were or are smokers and had comorbidities like diabetes. The groups were comparable at baseline.

The before and after surgery values of forced vital capacity (FVC), forced expiratory capacity ($FEVI_1$) and the peak expiratory flow rate (PEFR) were compared within the three intervention groups. When postoperative days 1–4 values were compared to preoperative day values, a statistically significant difference was found in most of the values in all three groups. Whereas, when postoperative day 7 values were compared to preoperative day values, no statistically significant difference was found in any of the values except FVC in the DB group. The FVC, FEV_1 and PEFR values for the volume incentive spirometry group almost reached the baseline on the postoperative day 7 ($p = 1.00$) (Table 2, Figure 4). Within-group comparisons of these three variables have been summarized in Table 2 and Figure 3. Significant differences were found in FVC values on comparing VS group with FS and DB group. Findings of between-group comparisons are summarized in Table 3.

The functional capacity of patients, measured using a 6-minute walk test (6MWT) on postoperative day 7, was compared between the three groups (Table 4). No statistical difference was found in the distance walked among the three groups. Similarly, functional difficulty questionnaire (FDQ) scores were taken on postoperative day 7 (Table 5 and Figure 5). Comparison between the groups showed a significant difference between the VS group and the other two groups (viz. FS and DB) ($p < 0.001$ and $p = 0.04$ respectively).

4. Discussion

Our study aimed at evaluating the effects of diaphragmatic breathing (DB), flow (FS) and volume-oriented incentive spirometer (VS) in patients who underwent open valve replacement surgery. To the best of our knowledge, this is the first study to compare the effects of three breathing techniques on pulmonary function, functional capacity and daily life functional tasks in patients following an open valve replacement surgery. The results of this study showed that all three techniques improved the pulmonary function test values in the postoperative period; however, the values of the volume spirometer group improved the most among the three groups. These patients in the volume spirometer group experienced the least difficulty in performing the activities of daily living involving thoracic movements. These results indicated that the volume spirometer could be a valuable treatment option for use with patients following open valve replacement surgeries for improving pulmonary function and many activities of daily living.

Pulmonary function test (PFT) values (FVC, FEV_1 and PEFR) decreased post-surgery when compared to the pre-surgery values. This decrease can be attributed to respiratory dysfunction due to the surgery. It involves shallow breathing in a monotonous pattern without a periodic sigh and dysfunction of the diaphragm induced by prolonged recumbent position [7]. Impaired mucociliary function and reduced cough effectiveness due to pain increase the risks related to retained pulmonary secretions which could lead to atelectasis. These impairments are caused due to various factors, such as smoking habits, comorbidities, administration of anaesthesia, duration of surgery and mechanical ventilation [7, 32].

Smoking is a risk factor for postoperative pulmonary complications, even in patients without any lung condition [8, 32]. Organ damage

Table 2. Comparison of FVC, FEV_1 and PEFR within the three intervention groups.

		FVC			FEV_1			PEFR		
		FS group	VS group	DB group	FS group	VS group	DB group	FS group	VS group	DB group
Mean ± SD										
Pre-op		1.59 ± 0.50	1.61 ± 0.41	1.51 ± 0.45	1.48 ± 0.63	1.26 ± 0.64	1.47 ± 0.63	2.55 ± 1.01	2.28 ± 1.03	2.56 ± 1.08
POD 1		0.63 ± 0.25	0.79 ± 0.33	0.54 ± 0.15	0.57 ± 0.19	0.54 ± 0.26	0.53 ± 0.14	0.92 ± 0.65	1.18 ± 0.66	0.77 ± 0.77
POD 2		0.70 ± 0.17	0.90 ± 0.37	0.62 ± 0.11	0.62 ± 0.18	0.63 ± 0.30	0.58 ± 0.16	1.10 ± 0.74	1.29 ± 0.70	0.73 ± 0.45
POD 3		0.78 ± 0.28	1.06 ± 0.43	0.66 ± 0.11	0.69 ± 0.21	0.71 ± 0.36	0.64 ± 0.18	1.28 ± 0.87	1.40 ± 0.72	0.87 ± 0.69
POD 4		0.90 ± 0.36	1.21 ± 0.44	0.74 ± 0.21	0.77 ± 0.24	0.80 ± 0.38	0.70 ± 0.22	1.42 ± 0.87	1.60 ± 0.71	1.11 ± 0.76
POD 5		0.89 ± 0.33	1.37 ± 0.45	0.75 ± 0.13	0.82 ± 0.29	0.79 ± 0.40	0.73 ± 0.26	1.49 ± 0.88	1.76 ± 0.83	1.18 ± 0.79
POD 6		1.03 ± 0.40	1.45 ± 0.43	0.83 ± 0.20	0.93 ± 0.33	0.99 ± 0.48	0.79 ± 0.27	1.47 ± 0.75	1.88 ± 0.90	1.22 ± 0.79
POD 7		1.14 ± 0.47	1.59 ± 0.40	0.94 ± 0.31	1.08 ± 0.41	1.13 ± 0.53	0.85 ± 0.30	1.56 ± 077	2.01 ± 0.91	1.27 ± 0.81
Difference between the means, % change and p value										
Pre-op vs. POD 1	Mean difference	0.96	0.82	0.97	0.91	0.71	0.94	1.63	1.10	1.78
	% Change	60.3	51.17	64.10	61.56	56.58	63.79	63.88	48.13	69.72
	p value	0.003	0.001	0.001	0.008	0.034	0.014	0.012	0.143	0.037
Pre-op vs. POD 2	Mean difference	0.89	0.71	0.88	0.86	0.63	0.89	1.45	1.00	1.82
	% Change	56.14	44.28	58.59	58.19	49.87	60.67	56.17	43.70	71.28
	p value	0.003	0.001	0.001	0.010	0.066	0.016	0.022	0.194	0.014
Pre-op vs. POD 3	Mean difference	0.81	0.55	0.85	0.79	0.55	0.84	1.28	0.88	1.69
	% Change	50.72	34.21	56.27	53.41	43.59	56.73	50.00	38.64	66.08
	p value	0.017	0.001	0.002	0.017	0.111	0.023	0.080	0.280	0.041
Pre-op vs. POD 4	Mean difference	0.69	0.40	0.77	0.71	0.46	0.77	1.13	0.69	1.44
	% Change	43.35	24.69	51.03	48.15	36.52	52.51	44.16	30.02	56.46
	p value	0.053	0.001	0.004	0.026	0.133	0.036	0.072	0.079	0.049
Pre-op vs. POD 5	Mean difference	0.70	0.24	0.76	0.67	0.46	0.74	1.06	0.52	1.38
	% Change	44.17	15.03	50.17	44.84	36.96	50.34	41.49	22.97	54.03
	p value	0.063	0.001	0.004	0.048	0.473	0.063	0.090	0.210	0.060
Pre-op vs. POD 6	Mean difference	0.56	0.16	0.68	0.55	0.26	0.68	1.08	0.40	1.34
	% Change	35.22	10.00	45.26	37.09	21.04	46.13	42.39	17.66	52.46
	p value	0.173	0.014	0.009	0.087	0.615	0.093	0.035	0.839	0.070
Pre-op vs. POD 7	Mean difference	0.44	0.03	0.57	0.41	0.13	0.63	0.99	0.27	1.28
	% Change	27.98	1.59	37.76	27.51	10.08	42.60	38.82	11.82	50.16
	p value	0.605	1.00	0.024	0.319	1.00	0.137	0.052	1.00	0.088

FS, Flow spirometry; VS, Volume spirometry; DB, Diaphragmatic breathing; FVC, Forced Vital Capacity; FEV_1, Forced expiratory volume in 1 s; PEFR, Peak expiratory flow rate; Pre-op, Preoperative day; POD, Postoperative day.

induced by tobacco, decreased lung capacity and reduced mucociliary function have been suggested as possible mechanisms for these complications [32]. Comorbidities like diabetes and hypertension could also contribute to cardiopulmonary complications [8]. Bucerius et al. found diabetes to be an independent risk factor for postoperative complications-like infection, reintubation, respiratory and renal insufficiency-in patients who underwent cardiac surgery [33]. Smoking and diabetes could also be responsible for delayed healing and increased chances of infection, thus delaying recovery in these patients [8, 32, 34].

Administration of anaesthetic agents leads to ventilation-perfusion mismatch which is a result of hypoventilation. Hypoxic ventilatory drive and the usual intermittent "sighing" respiration- which are necessary for maintaining normal lung inflation- are suppressed by narcotic analgesics. These changes could lead to postoperative pulmonary complications due to the lack of lung inflation [7].

In our study, the three breathing techniques (viz. VS, FS, DB) were distributed and analyzed among 3 groups (FS group, VS group and DB group). Our results depicted that all the techniques improved the pulmonary function test values (FVC, FEV_1, PEFR) over seven days. However, only FVC in the volume incentive spirometer group (VS group) almost reached back to the preoperative values, thereby showing better improvement. These results could be attributed to the effects of these techniques in improving lung volumes. Diaphragmatic breathing is shown to improve tidal volume, diaphragmatic excursion during inspiration and expiration and reduces accessory muscle activity [16].

An incentive spirometer allows a slow, long inspiration with an inspiratory hold, a phenomenon that is required for lung expansion. It also provides visual feedback giving a target to the patients [35]. In our study volume-oriented spirometer showed better results when compared to the flow-oriented incentive spirometer. This could be explained by the improved diaphragmatic activity and decreased work of breathing seen in volume spirometers when compared to flow spirometers [36]. A short sharp inspiration activates the flow-oriented incentive spirometers with a minimal increase in tidal volume. In a volume spirometer, however, an increase in tidal volume must be achieved before reaching a pre-set level. In a flow-oriented spirometer, air can be drawn in using accessory muscles whereas volume-oriented spirometers utilize diaphragmatic activity for drawing in the air [16].

These results are in accordance with the study done by Amin et al. which compared the effects of similar ventilatory techniques (VS, FS and DB) among patients who underwent coronary artery bypass graft surgery [26]. On comparing, the authors concluded that volume-oriented incentive spirometry exhibited better pulmonary function values as compared to the other two techniques. Another study that compared the effects of diaphragmatic breathing exercise and flow-oriented volume spirometer found no difference in the effects of the two techniques [37].

Six-minute walk test and functional difficulties questionnaire were found to be an effective and feasible mode of assessing the effects of the three techniques (FS, VS and DB) on functional capacity and activities of daily living involving thoracic movements in patients with cardiac

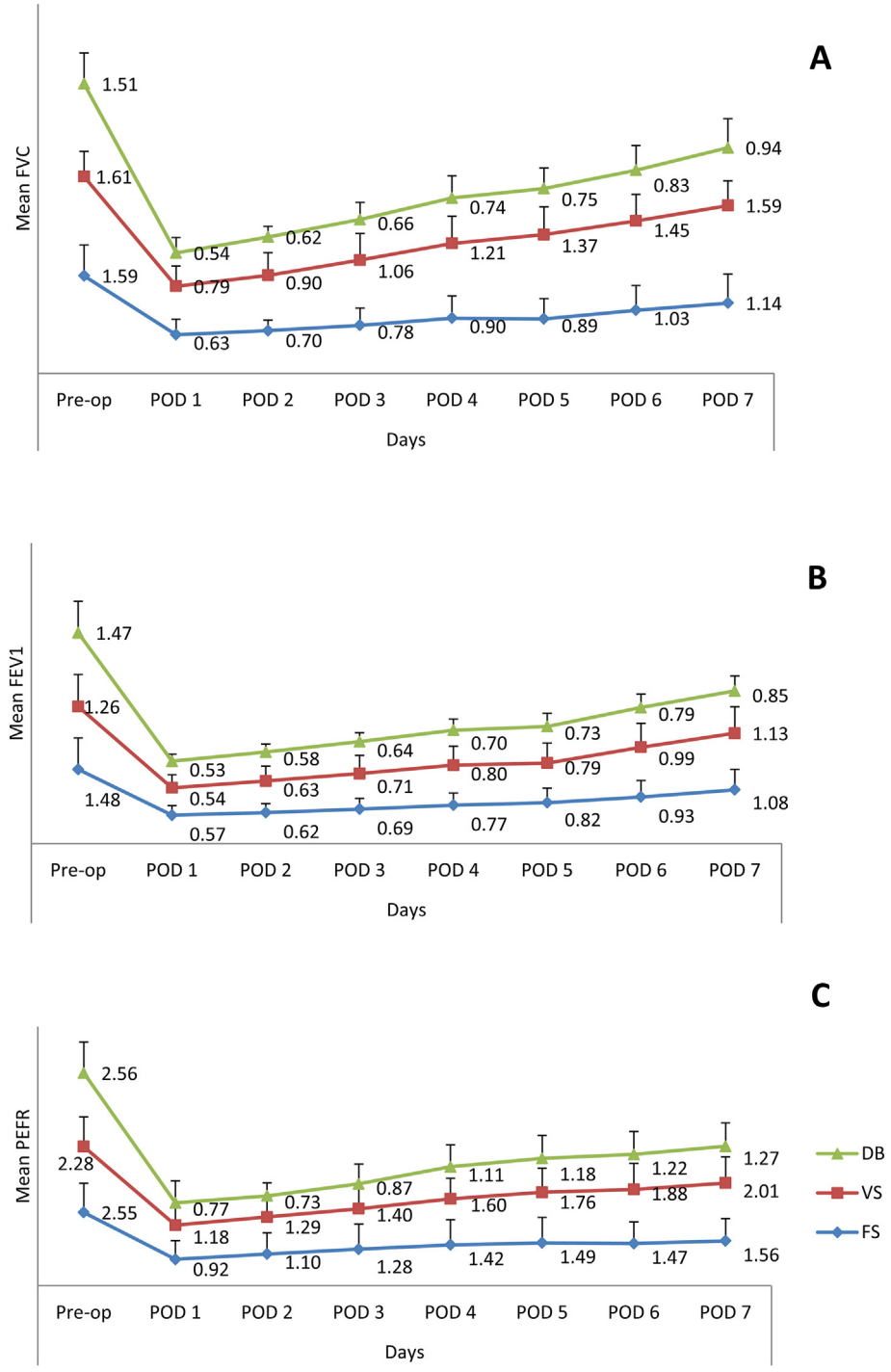

Figure 4. Comparative analysis of pulmonary function test values among flow spirometer (FS), volume spirometer (VS) and diaphragmatic breathing (DB) groups, before and after valve replacement surgery (n = 29). (A) Forced vital capacity (FVC), (B) Forced expiratory volume in 1 s (FEV_1), (C) Peak expiratory slow rate (PERF).

surgery [25, 38]. All three groups performed similarly in the 6-minute walk distance conducted on the seventh postoperative day. Functional difficulties score was significantly lesser in the volume-oriented incentive spirometer group indicating less difficulty in performing daily activities associated with thoracic movements. Similar results were obtained in the study done on coronary artery bypass graft surgery patients [26]. This could be due to the overall effects of improved pulmonary function in VS group when compared to the FS and DB group, thoracic mobility exercise, airway clearance techniques and early mobilization.

4.1. Contribution of airway clearance techniques and early mobilization in improving outcomes post-surgery

The airway clearance techniques and early mobilization administered in all three groups also contributed to the improvement in the overall patients' outcomes. Airway clearance techniques decrease retention of secretions, prevent alveolar collapse due to plug formation in the bronchioles and thus improve oxygenation by reducing ventilation-perfusion mismatch [7, 13]. Early mobilization improves mobility and helps the

Table 3. Comparison of FVC, $FEV_1$and PEFR among the three intervention groups.

		FS v/s VS			VS v/s DB			FS v/s DB		
		FVC	FEV_1	PEFR	FVC	FEV_1	PEFR	FVC	FEV_1	PEFR
Pre-op minus POD 5	Mean difference	0.45	0.20	0.53	0.51	0.27	0.85	0.05	0.07	0.32
	p value	0.04	1.00	0.50	0.02	0.72	0.09	1.00	1.00	1.00
Pre-op minus POD 7	Mean difference	0.41	0.28	0.72	0.54	0.50	1.01	0.12	0.21	0.29
	p value	0.06	0.47	0.15	0.01	0.47	0.02	1.00	0.76	1.00

FS, Flow spirometry; VS, Volume spirometry; DB, Diaphragmatic breathing; FVC, Forced Vital Capacity; FEV_1, Forced expiratory volume in 1 s; PEFR, Peak expiratory flow rate; Pre-op, Preoperative day; POD, Post-operative day.

Table 4. Comparison of distance walked during the 6-Minute walk test (6MWT) among the three intervention groups.

	Flow Incentive Spirometer group (FS)	Volume Incentive Spirometer group (VS)	Diaphragmatic breathing group (DB)
6 Minute walk distance Postoperative day 7 (metres)	108.0 ± 40.49	135.5 ± 46.66	97.0 ± 59.07
Comparison between the groups			
	FS v/s VS	**VS v/s DB**	**FS v/s DB**
Mean difference	27.55	38.55	11.00
p value	0.70	0.30	1.00

Table 5. Comparison of Functional difficulty questionnaire scores (FDQ) among the three intervention groups.

	Flow Incentive Spirometer group (FS)	Volume Incentive Spirometer group (VS)	Diaphragmatic breathing group (DB)
Postoperative day 7	81.0 ± 21.83	52.22 ± 31.92	98.00 ± 16.86
Comparison between the groups			
	FS v/s VS	**VS v/s DB**	**FS v/s DB**
Mean difference	28.77	45.77	17.00
p value	0.04	0.001	0.37

patients to maintain an upright posture which enhances the lung volumes. It also decreases the postoperative effects of anaesthesia (reduction in lung function and secretion retention) and deleterious effects of surgery (pain and reduced chest expansion) on the cardiopulmonary system [7, 13]. Santos et al. reported that early mobilization improved functional capacity post-cardiac surgery [39].

4.2. Adherence to the exercises post-surgery

All the patients included in the study were given a set of exercises to be performed every two hours. Their caretakers were briefed about these exercises and provided with individual logbooks to maintain records. This helped us to track patients' adherence to the exercises for the first seven days after surgery.

4.3. Limitations

Our study was a pilot study performed on a small number of patients to assess the feasibility of the study technique in open valve replacement surgery. Only short-term effects of the interventions were studied. Although the VS technique was superior and can be explained by a positive effect of the improved diaphragm muscle recruitment, muscular strength or electrical activity of the diaphragm was not evaluated in this study. Most of the patients were smokers or ex-smokers and had comorbidities but their effects on the various outcomes were not studied. In addition, duration of anaesthesia, duration of intubation and severity of pain post-surgery, analgesics, bronchodilators and types of airway clearance techniques used were not documented.

4.4. Future research

Further research could be performed using the same protocol in the same population with larger sample size. Patients could also be stratified based on smoking habits (non-smokers, current smokers and ex-smokers) and the presence of comorbidities (hypertension and diabetes). Long-term effects of diaphragmatic breathing, flow and volume-oriented spirometers can be evaluated using various outcome measures in patients following valve replacement surgery. Future research with control groups could also be conducted for comparing various other breathing techniques in valve replacement surgery patients.

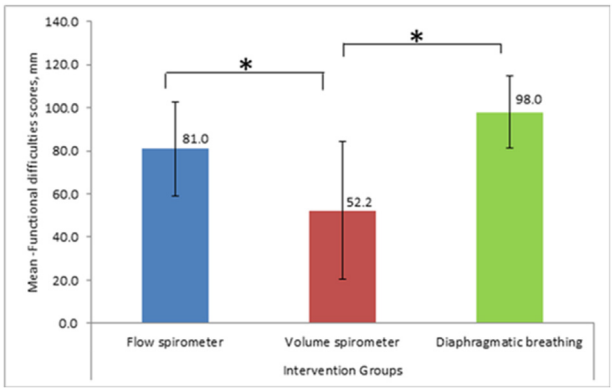

Figure 5. Comparison of functional difficulty questionnaire (FDQ) scores, taken on postoperative day 7, among the three intervention groups. *Significant difference shown between the groups ($p < 0.05$).

5. Conclusion

Based on the findings of our study, we conclude that using diaphragmatic breathing, flow or volume-oriented spirometers could improve pulmonary function in the postoperative period, in patients following valve replacement surgery. The volume-oriented spirometer, however, was found to be the most beneficial of the three techniques. It also improved daily life functional tasks associated with thoracic movements when compared to the flow-oriented spirometer and diaphragmatic breathing. Further studies with a larger sample size are required to confirm these findings.

Declarations

Author contribution statement

Gopala Krishna Alaparthi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Harish Raghavan: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Revati Amin: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Aishwarya Gatty: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Kalyana Chakravarthy Bairapareddy, Vaishali K., Audrey Borghi-Silva and Fatma A. Hegazy: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

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