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ORIGINAL RESEARCH

Volume Incentive Spirometry Reduces Pulmonary Complications in Patients After Open Abdominal Surgery: A Randomized Clinical Trial

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Objective: To compare the effect of diaphragmatic breathing and volume incentive spirometry (VIS) on hemodynamics, pulmonary function, and blood gas in patients following open abdominal surgery under general anesthesia.

Methods: A total of 58 patients who received open abdominal surgery were randomly assigned to the control group (n=29) undergoing diaphragmatic breathing exercises and the VIS group (n=29) undergoing VIS exercises. All the participants performed the six-minute walk test (6MWT) preoperatively to evaluate their functional capacity. Hemodynamic indexes, pulmonary function tests, and blood gas indexes were recorded before surgery and on the 1st, 3rd, and 5th postoperative day.

Results: The functional capacity was not significantly different between the two groups during the preoperative period ($P > 0.05$). At 3 days and 5 days postoperatively, patients in the VIS group had a significantly higher SpO2 than that in the control group ($P < 0.05$). Pulmonary function test values were reduced in both two groups postoperatively when compared to the preoperative values but improved for three and five days afterward ($P < 0.05$). Of note, the significantly elevated levels of peak expiratory flow (PEF), forced expiratory volume in the first second (FEV1), forced vital capacity (FVC), and FEV1/FVC ratio were observed on the 1st, 3rd, and 5th postoperative days in the VIS group compared with those in the control group ($P < 0.05$). Besides, bass excess (BE), and pH values were significantly higher in the VIS group on the 1st postoperative day than those in the control group ($P < 0.05$).

Conclusion: Diaphragmatic breathing and VIS could improve postoperative pulmonary function, but VIS exercise might be a better option for improving hemodynamics, pulmonary function, and blood gas for patients after open abdominal surgery, hence lowering the incidence of postoperative pulmonary complications.

Keywords: diaphragmatic breathing, volume incentive spirometry, hemodynamics, pulmonary function, blood gas, open abdominal surgery

Introduction

More than 300 million surgical procedures are performed every year worldwide, and abdominal surgery is the most frequent major surgery.[1,2] Postoperative pulmonary complications (PPCs) following abdominal surgery are frequent with an incidence ranging from 1% to 30%.[3] The risk of PPCs increases with the distance from the surgical site to the diaphragm. Due to this unique physiological mechanism, upper abdominal incisions are associated with a higher risk of PPCs than lower abdominal surgeries.[3] Common PPCs include atelectasis, pneumonia, and hypoxemia partially caused by diaphragm dysfunction, impaired mucociliary clearance, and postoperative pathophysiological reductions in lung volumes such as a reduction in the forced vital capacity (FVC) and forced expiratory volume in the first second (FEV1).[4,5] It has been demonstrated that obesity, smoking, malnutrition, and old age were associated with the incidence of PPCs among those undergoing abdominal surgery. Besides, the anesthesia, the surgical technique, the type of incision, and ineffective coughing might also contribute to PPC development.[6] PPCs increase the morbidity and mortality rate, the

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length of hospital stay, readmissions, and additional healthcare costs.[7] Therefore, to take effective measures for the prevention of PPCs after abdominal surgeries are urgently needed.

Since the beginning of the 20th century, respiratory physical therapy is often used for PPCs prevention and treatment to strengthen ventilation-perfusion matching and increase lung volumes and airway clearance.[8] It consists of various airway clearance techniques and lung expansion therapy including diaphragmatic breathing exercises, mobilization, and mechanical breathing devices such as incentive spirometry.[9] Diaphragmatic breathing exercise increases diaphragmatic excursion, alveolar expansion, and ventilation, reducing the chance of hypoxemia and an increase in respiratory work.[10] Incentive spirometry is designed to give positive feedback and enables the patient to take long, slow deep breaths imitating natural sighing.[11] It is available in two types: flow incentive spirometry (FIS) and volume incentive spirometry (VIS).[11] A previous study has compared the effect of FIS and VIS on pulmonary function in abdominal surgery and found that VIS had a superior ability to FIS in reducing hospital stay.[12] Additionally, Sum et al revealed that incentive spirometer reduced PPCs in patients with traumatic rib fractures.[13] However, there is a lack of comprehensive research comparing diaphragmatic breathing with VIS in subjects after abdominal surgeries. In this study, we divided patients into the control (receiving diaphragmatic breathing exercises) and VIS (performing VIS exercises) groups to compare the hemodynamics, pulmonary function, and blood gas. Understanding the different effects of the two exercises might aid in recovery planning for patients after open abdominal surgeries.

Materials and Methods

Participants

This prospective and randomized study was conducted in the Department of Surgery, Haining People's Hospital between August 2021 and September 2022. Ethics approval was obtained from the Institutional Ethics Committee (IEC HPH 221008). All participants signed the written informed consent. Inclusion criteria: (1) patients received open abdominal surgery under general anesthesia; (2) with a medium or high risk of postoperative pulmonary complications ("Assess Respiratory Risk in Surgical Patients in Catalonia, ARISCAT score" ≥ 26);[14] (3) patients who did not stay in intensive care unit after an operation and returned to ward successfully after extubation; (4) good compliance and understanding ability, able to cooperate with the completion of perioperative pulmonary rehabilitation treatment. Finally, 58 participants met the criteria and participated in this study. All the participants were randomly divided into the control group (n=29) and the VIS group (n=29) (Figure 1). The allocation sequence was computer-generated by a statistician and blinded to the investigators. Participants were randomized at a ratio of 1:1. The outcome assessor was also blinded to the group assignment.

Intervention

In the control group, participants received conventional diaphragmatic breathing exercises. The participants were placed in a half-lying position and their hands were placed just below the anterior costal margin, on the rectus abdominus muscle, and inhaled slowly through the nose for 3 seconds, from functional remaining capacity to total lung capacity. Exhalation was performed slowly through the mouth. They were asked to relax their shoulders and upper chest so they could feel the rise and fall of their abdomen with the hand resting on it.[15] The method of performing diaphragmatic breathing exercises is shown in Figure 2A. The exercises were performed for 5 minutes and 4 times per day under the supervision of the therapist. They were asked to breathe normally in between the sets of the diaphragmatic breathing exercise.[11]

In the VIS group, VIS was administered to the patient who was also placed in a half-lying position. A pillow was placed beneath the patient's knees. The participants were instructed to hold the volume-oriented incentive spirometry and perform slow, deep inhalation, avoiding any forceful expiration.[16] The process was first demonstrated to the patient to ensure that they understood the technique's use before performing it. The method of performing VIS is shown in Figure 2B. The treatment was performed for 5 minutes and 4 times per day under the supervision of the therapist. Both two groups received routine postoperative rehabilitation education before surgery and began to receive treatment guidance 2 days before surgery.

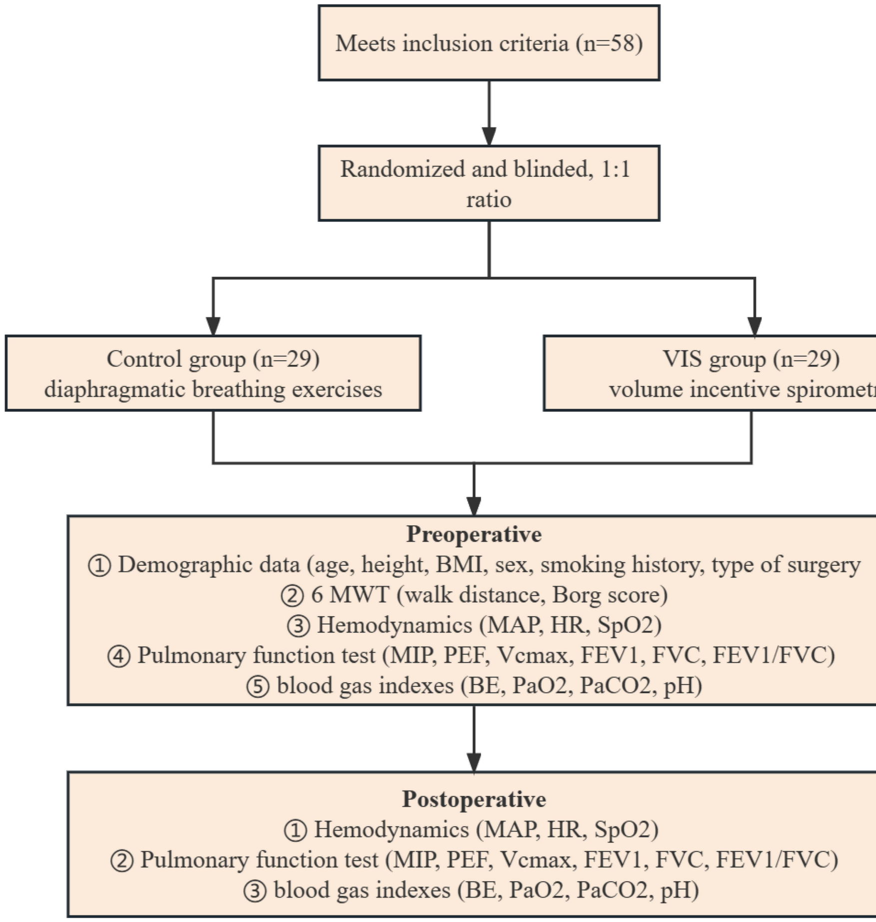

Figure 1 Consort flow chart.

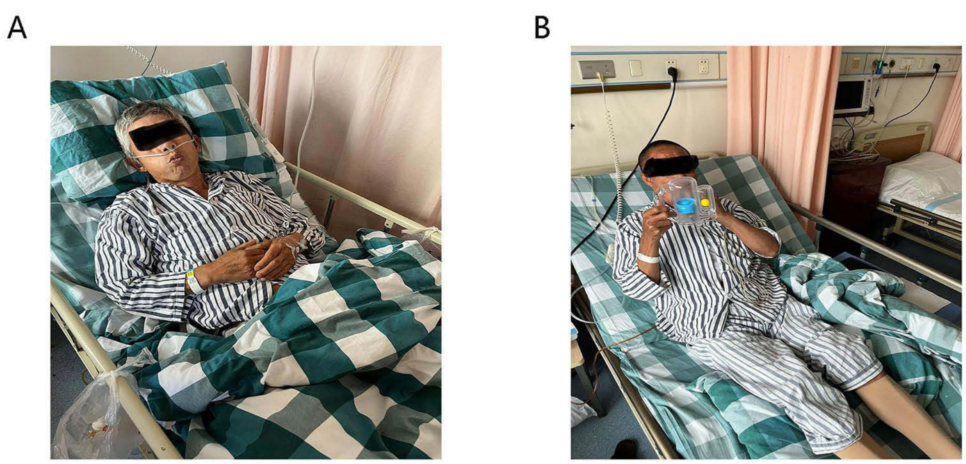

Figure 2 Two intervention exercises for patients following abdominal surgery. (**A**) Diaphragmatic breathing. (**B**) Volume incentive spirometry.

Data Collection

After being allotted into groups, the patients in the two groups were visited one day before the surgery. Demographic data such as age, height, weight, body mass index (BMI), sex, smoking history, and type of surgery were collected.

Six-minute walk test (6MWT): The patients performed a 6MWT according to the American Society's guidelines during the preoperative period.[17] Dyspnoea and fatigue, mean arterial pressure (MAP), heart rate (HR), and oxygen saturation (SpO2) were measured at the start and immediately after finishing the test. A modified Borg scale was used to measure dyspnoea and fatigue. Distance covered in meters after 6 minutes was the main outcome of the test.

All the subjects underwent evaluations of hemodynamic indexes including MAP, HR, and SpO2 were also recorded on the 1st, 3rd, and 5th postoperative days for both groups. The primary outcome measurements were changes to pulmonary function through the following parameters: maximal inspiratory pressure (MIP), peak expiratory flow (PEF), vital capacity max (Vcmax), FEV1, FVC, and FEV1/FVC. In addition, blood gas indexes such as bass excess (BE), partial pressure of arterial oxygen (PaO2), partial pressure of arterial carbon dioxide (PaCO2), and pH values were recorded. These measurements were taken in the preoperative period and were repeated on the 1st, 3rd, and 5th postoperative days for both groups.

Statistical Analysis

All data analyses were performed by SPSS software version 23.0 (SPSS Inc., Chicago, IL, USA). Categorical variables were represented as count (percentage) and the difference between the two groups was compared by Chi-square test or Fisher's exact test. Continuous variables conforming to normal distribution were expressed as mean ± standard deviation (SD) and an independent *t*-test was used to compare differences between the two groups, and repeated-measure analysis of variance was used for intra-group comparisons. Non-normally distributed continuous data were expressed as median (quartile) and were compared by Mann–Whitney *U*-test between the two groups. Statistical significance was set at $P < 0.05$. The effect size of the study was calculated as 0.80 using G*Power software version 3.1.9.7 (Franz Faul, Universitat Kiel, Germany) based on the two-sided significance level (α), sample size (n=29 in each group), power (1-β=0.85), and independent *t*-test.

Results

Demographic Information

Fifty-eight patients (including 41 males and 17 females) who received open abdominal surgery under general anesthesia were included in the study. The control group and the VIS group consisted of 29 patients each. There were no dropouts in this study. Their average age was 72.81±9.86 years (control group 72.00 ± 9.62; VIS group 73.62 ± 10.21; $P > 0.05$). There were no significant differences in height, weight, and BMI between the two groups (all $P > 0.05$). Males accounted for 72.4% and 69.0%, respectively in the control and VIS groups with no statistical difference ($P > 0.05$). The number of patients having a smoking history was 19 (65.5%) and 15 (51.7%) in the control and VIS groups, respectively ($P > 0.05$). Besides, the distribution of type of surgery in the control group was not significantly different from that in the VIS group (Table 1).

Comparison of Functional Capacity Between the Two Groups Preoperatively

The functional capacity of patients was measured using a 6MWT preoperatively and was compared between the two groups. No significant difference was observed in the distance walked between the two groups. Additionally, the pre-test modified Borg score, MAP, HR, and SpO2, as well as the post-test modified Borg score, MAP, HR, and SpO2 in the two groups were not significantly different (all $P > 0.05$) (Table 2).

Comparison of Hemodynamics Inter and Intra-Group Differences at Different Time Points

Three hemodynamic indexes MAP, HR, and SpO2 were compared with the control and VIS groups 1, 3, and 5 days after the operation. When compared with the 1st postoperative day, there was a statistically significant increase seen in the MAP on the 3rd and 5th days within the two groups (all $P < 0.05$). There was a statistically significant decrease in HR on the 3rd postoperative day compared with the 1st postoperative day ($P < 0.05$). However, there was no significant change in SpO2 postoperatively ($P > 0.05$). Besides, at 3 days and 5 days after the operation, patients in the VIS group had a significantly higher SpO2 than that in the control group (all $P < 0.05$) (Table 3).

Table 1 Demographic Characteristics

Variables	Control Group (n=29)	VIS (n=29)	P-value
Age (years)	72.00 ± 9.62	73.62 ± 10.21	0.536
Height (m)	1.63 ± 0.07	1.64 ± 0.07	0.656
Weight (kg)	59.45 ± 7.73	61.90 ± 10.37	0.313
BMI (kg/m^2)	22.38 ± 2.55	23.00 ± 3.04	0.402
Sex			0.773
Male	21 (72.4)	20 (69.0)	
Female	8 (27.6)	9 (31.0%)	
Smoking history			0.286
No	10 (34.5)	14 (48.3)	
Yes	19 (65.5)	15 (51.7)	
Type of surgery			0.753
Gastrointestinal	23 (79.3)	22 (75.9)	
Urology	6 (20.7)	7 (24.1)	

Notes: A chi-square test and an independent *t*-test were used to compare the differences between the two groups.
Abbreviations: VIS, volume incentive spirometry; BMI, body mass index.

Table 2 Comparison of Functional Capacity Between the Two Groups Preoperatively

Variables	Control Group (n=29)	Volume Incentive Spirometry (n=29)	P-value
Walk distance (m)	369.71 ± 93.24	350.63 ± 108.57	0.476
Pre-test Borg score	0.21 ± 0.49	0.17 ± 0.60	0.812
Post-test Borg score	2.24 ± 1.06	2.35 ± 1.45	0.757
Pre-test MAP (mmHg)	92.24 ± 10.23	94.05 ± 13.05	0.561
Post-test MAP (mmHg)	96.13 ± 12.11	103.62 ± 18.50	0.073
Pre-test HR (BPM)	83.05 ± 8.77	82.90 ± 15.05	0.963
Post-test HR (BPM)	94.68 ± 9.07	95.24 ± 15.38	0.866
Pre-test SpO2 (%)	97.65 [97.56, 98.33]	97.63 [95.00, 98.00]	0.118
Post-test SpO2 (%)	97.59 ± 1.56	96.79 ± 2.18	0.116

Notes: An independent *t*-test and Mann–Whitney *U*-test were used to compare the differences between the two groups.

Table 3 Comparison of Hemodynamics Inter and Intra-Group Differences at Different Time Points

	Group	T1	T3	T5
MAP (mmHg)	Control (n=29)	79.08 ± 8.34	83.94 ±7.65$^{\#}$	90.22 ±8.07$^{\#}$
	VIS (n=29)	83.08 ± 14.97	87.40 ±13.33$^{\#}$	91.85 ±11.39$^{\#}$
	P-value	0.216	0.231	0.533
HR (BPM)	Control (n=29)	84.62 ±11.43	75.98 ±7.38$^{\#}$	79.26 ±7.54
	VIS (n=29)	79.66 ± 15.48	76.93 ±12.87$^{\#}$	78.62 ±12.70
	P-value	0.170	0.733	0.818
SpO2 (%)	Control (n=29)	98.19 ±1.34	97.40 ±2.06	98.35 ±0.83
	VIS (n=29)	98.38 ±2.41	98.66 ±0.77	98.94 ±1.06
	P-value	0.719	0.004*	0.021*

Notes: An independent *t*-test was used for intergroup comparisons. Compared with the control group, *P <0.05. Repeated-measure analysis of variance was used for intra-group comparisons. Compared with T1, $^{\#}$P <0.05. T1: postoperative day 1, T3: postoperative day 3, T5: postoperative day 5.

Table 4 Comparison of Pulmonary Function Test Inter and Intra-Group Differences at Different Time Points

	Group	T0	T1	T3	T5
MIP (cmH_2O)	Control (n=29)	52.50±10.28	17.63±2.67#	34.21±12.65#	35.34±4.75#
	VIS (n=29)	51.75±12.87	22.61±5.10#	36.56±7.19#	44.20±8.59#
	P-value	0.807	<0.001*	0.389	<0.001*
PEF (L/min)	Control (n=29)	249.20±44.24	77.98±16.66#	107.89±26.57#	144.25±30.18#
	VIS (n=29)	227.81±72.85	98.62±22.23#	148.48±36.81#	167.68±42.77#
	P-value	0.183	<0.001*	<0.001*	0.019*
Vcmax (L)	Control (n=29)	2.03±0.53	0.73±0.14#	0.88±0.12#	1.17±0.24#
	VIS (n=29)	1.89±0.65	0.81±0.18#	1.11±0.36#	1.41±0.43#
	P-value	0.371	0.062	0.003*	0.011*
FEV1 (L)	Control (n=29)	1.39±0.40	0.37±0.09#	0.47±0.09#	0.56±0.09#
	VIS (n=29)	1.20±0.46	0.62±0.31#	0.74±0.34#	0.86±0.39#
	P-value	0.094	<0.001*	<0.001*	<0.001*
FVC (L)	Control (n=29)	1.95±0.56	0.82±0.18#	0.97±0.18#	1.06±0.17#
	VIS (n=29)	1.82±0.64	1.15±0.49#	1.30±0.52#	1.44±0.56#
	P-value	0.428	0.002*	0.002*	0.001*
FEV1/FVC (%)	Control (n=29)	71.73±6.70	45.18±6.40#	49.44±5.78#	53.32±5.47#
	VIS (n=29)	67.58±17.95	55.07±14.91#	58.04±14.48#	60.90±14.81#
	P-value	0.251	0.002*	0.005*	0.014*

Notes: An independent *t*-test was used for intergroup comparisons. Compared with the control group, *P <0.05. Repeated-measure analysis of variance was used for intra-group comparisons. Compared with T0, #P <0.05. T0: preoperatively, T1: postoperative day 1, T3: postoperative day 3, T5: postoperative day 5.

Comparison of Pulmonary Function Inter and Intra-Group Differences at Different Time Points

No significant difference in MIP, PEF, Vcmax, FEV1, FVC, and FEV1/FVC between the control and VIS groups was found during the preoperative period (P >0.05). Compared with the preoperative period, MIP, PEF, Vcmax, FEV1, FVC, and FEV1/FVC were significantly decreased on the 1st, 3rd, and 5th postoperative day within both control and VIS groups (all P <0.05). However, there was an increasing trend in these six indexes on the 3rd and 5th postoperative days compared with the 1st postoperative day. Moreover, the VIS group had a significantly higher value of MIP than the control group on the 1st and 5th days after the operation (P <0.05). The Vcmax value was significantly higher in the VIS group on the 3rd and 5th postoperative days than that in the VIS group (P <0.05). The significantly elevated levels of PEF, FEV1, FVC, and FEV1/FVC were observed on the 1st, 3rd, and 5th postoperative days in the VIS group compared with those in the control group (all P <0.05) (Table 4).

Comparison of Blood Gas Indexes Inter and Intra-Group Differences at Different Time Points

There was no statistical difference in preoperative blood gas indexes between the two groups. Compared with the preoperative period, BE, PaO2, and pH were significantly downregulated on the 1st and 3rd days after the operation within the two groups (P <0.05). The level of PaCO2 was significantly upregulated on the 1st and 3rd postoperative days compared to the preoperative period (P <0.05). In the VIS group, BE, and pH were significantly higher on the 1st postoperative day than those in the control group (P <0.05), while there was no statistical significance in PaO2 and PaCO2 levels between the two groups (P >0.05) (Table 5).

Discussion

With a large number of surgeries occurring annually worldwide, morbidity and mortality are increased in patients who develop PPCs.[18] PPCs such as respiratory failure, and pneumonia are common following abdominal surgery, leading to a prolonged hospital stay and decreased postoperative stay.[19] This study compared the efficacy of conventional

Table 5 Comparison of Blood Gas Indexes Inter and Intra-Group Differences at Different Time Points

	Group	T0	T1	T3	T5
BE (mmol)	Control (n=29)	−1.07±4.85	−2.71±1.21#	−1.75±0.48#	−1.09±1.04
	VIS (n=29)	1.53±6.42	−0.89±1.40#	−1.93±2.31#	−0.79±3.43
	P-value	0.087	<0.001*	0.690	0.657
PaO2 (mmHg)	Control (n=29)	115.89±35.96	102.93±28.55#	108.25±27.47#	117.90±10.85
	VIS (n=29)	146.54±98.94	126.74±79.62#	139.15±85.67#	120.24±59.48
	P-value	0.126	0.138	0.073	0.836
PaCO2 (mmHg)	Control (n=29)	37.50±4.70	38.51±4.19#	37.89±4.42#	37.77±1.02
	VIS (n=29)	39.53±5.02	40.37±4.85#	39.79±4.91#	39.01±3.27
	P-value	0.116	0.124	0.128	0.059
pH	Control (n=29)	7.40±0.05	7.34±0.01#	7.38±0.01#	7.40±0.01
	VIS (n=29)	7.40±0.06	7.35±0.02#	7.37±0.03#	7.39±0.03
	P-value	0.919	0.024*	0.176	0.314

Notes: An independent *t*-test was used for intergroup comparisons. Compared with the control group, *P <0.05. Repeated-measure analysis of variance was used for intra-group comparisons. Compared with T0, #P <0.05. T0: preoperatively, T1: postoperative day 1, T3: postoperative day 3, T5: postoperative day 5.

diaphragmatic breathing and the VIS on hemodynamics, pulmonary function, and blood gas indexes in patients undergoing open abdominal surgery under general anesthesia. The study enrolled 58 participants with an average age of 72.81 ±9.86 years. The patients were randomly assigned to the control group receiving the diaphragmatic breathing exercise (n=29) and the VIS group (n=29). Our study indicated that VIS might be a valuable treatment option for use with patients after open abdominal surgeries for improving pulmonary function, hemodynamics, and blood gas indexes.

Many risk factors have been identified to be associated with PPCs. Smoking is a risk factor for pulmonary complications after surgery, even in patients with the absence of lung disease.[20] The underlying mechanism might be decreased lung capacity and impaired mucociliary function due to tobacco-induced organ damage.[21] In addition, older age was associated with a higher risk of PPCs and poor survival rates since they are at an increased risk of comorbid conditions.[22] Congestive heart failure, a diagnosis of chronic obstructive pulmonary disease, an ASA score of II or higher, or chronic liver disease were independent risk factors for PPCs.[5,23–25] Kaw et al showed that patients with obstructive sleep apnoea have a two-fold increase in the risk of developing acute respiratory failure after non-cardiac surgery.[26] In addition, patients with preoperative anemia undergoing any type of surgery are more than triple as likely as those without anemia to develop a PPC.[27]

The administration of anesthesia leads to ventilation-perfusion mismatch, hypoxemia, and shunt. The hypoxic ventilator drive and the normal periodic "sighing" respiration which are necessary for the maintenance of normal lung inflation are suppressed by narcotic analgesics and anesthetic agents.[28] Narcotic analgesics affect the central regulation of respiration, altering the upper respiratory tract and chest wall, resulting in inadequate ventilation, reduced sensitivity of the respiratory center to carbon dioxide stimulation, increased obstructive breathing, suppression of the cough reflex, and irregular mucus production.[10] Direct injuries to the abdominal wall and incisions affect diaphragm function. All these factors can impair the function of respiratory muscles, leading to a decrease in functional residual capacity and vital capacity.[29] In this study, the functional capacity of the patients preoperatively was assessed by 6MWT and the results showed that there was no significant difference in all the related indicators including walk distance, Borg-score, MAP, HR, and SpO2 between the two groups. However, SpO2 in the VIS group was significantly higher than that in the control group on the 3rd and 5th postoperative day, indicating that postoperative hypoxemia was reduced by using VIS.

FEV1, FVC, and FEV1/FVC are useful parameters for evaluating restrictive lung disease. PEF is a measure of maximum flow or peak flow generated by maximum effort on exhalation and it assesses maximum expiratory as an alternative measure of expiratory muscle strength and is useful for evaluating obstructive pulmonary disease such as asthma.[30] The pulmonary function test values such as PEF, FEV1, FVC, and FEV1/FVC ratio were all significantly downregulated after abdominal surgery compared with those during the preoperative period. As a mechanical device, VIS was used to encourage patients to take long, slow, and sustained deep inspirations which contribute to achieving maximal inflating pressure in the alveoli and maximal inhaled volume, and also helps to maintain the patency of the smaller airways.[11] There is an increasing trend of these values after diaphragmatic breathing exercises and VIS exercises on the 3rd and 5th postoperative day. As expected, patients in the VIS group had significantly higher levels of FEV1, FVC, FEV1/FVC, MIP, PEF, and Vcmax compared with the control group. Moreover, we found that BE and pH values were higher in the VIS group within the normal range than those in the control group. These findings revealed that VIS exercise might have a superior ability to the conventional diaphragmatic breathing exercise in improving pulmonary function.

In conclusion, the functional capacity of the patients in the two groups was not statistically different before the surgery. There was a significant improvement in hemodynamics, pulmonary function, and blood gas for patients following open abdominal surgery in the VIS group to the control group. Thus, diaphragmatic breathing and VIS could improve pulmonary function postoperatively, but VIS exercise might be a better option for lowering the incidence of PPCs.

Data Sharing Statement

The dataset used and/or analyzed during the current study is available from the corresponding author on reasonable request.

Ethics Approval

The study was approved by Haining People's Hospital. All patients who were familiar with the contents and processes of the study and able to complete all the scheduled study processes signed the informed consent. Our study complies with the Declaration of Helsinki.

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Disclosure

The authors have no conflicts of interest to declare for this work.

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