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Research Article

Application Effectiveness of Breathing Training Devices in Postoperative Patients with Lung Cancer

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Abstract

Objective: This study aims to investigate the application effectiveness of a self-developed portable lung function respiratory training device in rehabilitation training for elderly lung cancer patients after surgery. **Methods:** A total of 100 patients diagnosed with lung cancer and undergoing lung resection surgery between 2022 and 2023 in three tertiary hospitals in Hainan Province, China, were randomly divided into control and research groups. Patients in the control group underwent traditional respiratory muscle rehabilitation training, while patients in the research group used the self-developed portable lung function respiratory training device in addition to traditional respiratory muscle rehabilitation training. The first-second forced expiratory volume (FEV1) and forced vital capacity (FVC) were compared between the two groups. **Results:** On the 7th day postoperatively, there was a statistically significant difference in both FEV1 and FVC between the experimental and control groups ($P < 0.05$). **Conclusion:** The application of the self-developed portable lung function respiratory training device in rehabilitation training for lung cancer patients after surgery effectively improves pulmonary function indices, enhances respiratory muscle strength, and promotes postoperative lung function recovery.

Keywords: lung cancer, pulmonary function indices, respiratory training, training device

Introduction

Lung cancer is currently one of the malignant tumors with high incidence and mortality rates globally. Lung resection surgery is the preferred and primary treatment modality for lung cancer patients in clinical practice (Siegel *et al.,*2023). Surgery can prolong overall survival, delay disease progression, and improve survival rates. However, postoperative complications such as pain, fatigue, advanced age, improper coughing and sputum clearance methods, can lead to decreased lung function, respiratory complications such as lung infections, atelectasis, respiratory distress, and respiratory failure in 38%-58% of patients, resulting in prolonged hospitalization, increased rates of cancer recurrence, readmission within 30 days, and mortality, all of which affect prognosis (Gouvinhas *et al.,* 2018; Huang *et al.,* 2017; Lai *et al.,* 2017; Huang *et al.,* 2018; NCCN guidelines: non-small cell lung cancer).

Research shows that respiration is crucial for maintaining the normal functioning of the body's organ systems. Aimed at preventing and intervening in postoperative complications, the purpose of respiratory training is to correct compensatory breathing patterns, rebuild proper breathing techniques, increase the relaxation and contraction capacity of respiratory muscle groups, improve alveolar ventilation and gas exchange (Garcia *et al.,*2016), enhance postoperative lung function

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levels, prevent collapse of small airways, reduce the risk of lung infections, shorten hospital stays and chest tube placement times, and improve quality of life and exercise tolerance.

In this study, we designed a portable lung function respiratory training device and conducted preliminary clinical trials. We compared the changes in pulmonary function indices FEV1 and FVC after intervention therapy with this device on the third and seventh days postoperatively in lung cancer patients. Furthermore, we observed the application effectiveness of this device in respiratory muscle and pulmonary function rehabilitation training.

Materials and Methods

Device Structure

Figures 1A and 1B respectively illustrate the schematic and physical diagrams of the portable lung function respiratory training device used in this study. The device comprises a base, lifting structure, transparent tube, first valve, blowing mouthpiece, second valve, connecting tube, and balloon. The second valve is a bidirectional valve through which water can flow into the balloon due to blowing pressure. After blowing stops, the water in the balloon flows back into the transparent tube due to atmospheric pressure. The first valve is a unidirectional non-return valve designed with a check valve to prevent water backflow, thereby blocking water from flowing back from the transparent tube to the blowing mouthpiece, preventing patient choking. The lifting structure addresses the inconvenience of existing pulmonary function rehabilitation devices for users of different heights and positions, such as supine, semi-recumbent, and sitting positions. The blowing mouthpiece and balloon are made of disposable materials and can be replaced at any time. The transparent tube can hold tap water with graduated markings, allowing selection of different water capacities according to patient needs. The markings on the transparent tube, water height, and balloon size provide real-time feedback on patient pulmonary function performance, enhancing patient training motivation. The device operates without the need for computers or smartphone smart devices, making it simple to use. This device has obtained a utility model patent in China (ZL 2021 2 0304303.8) and has been designed and produced.

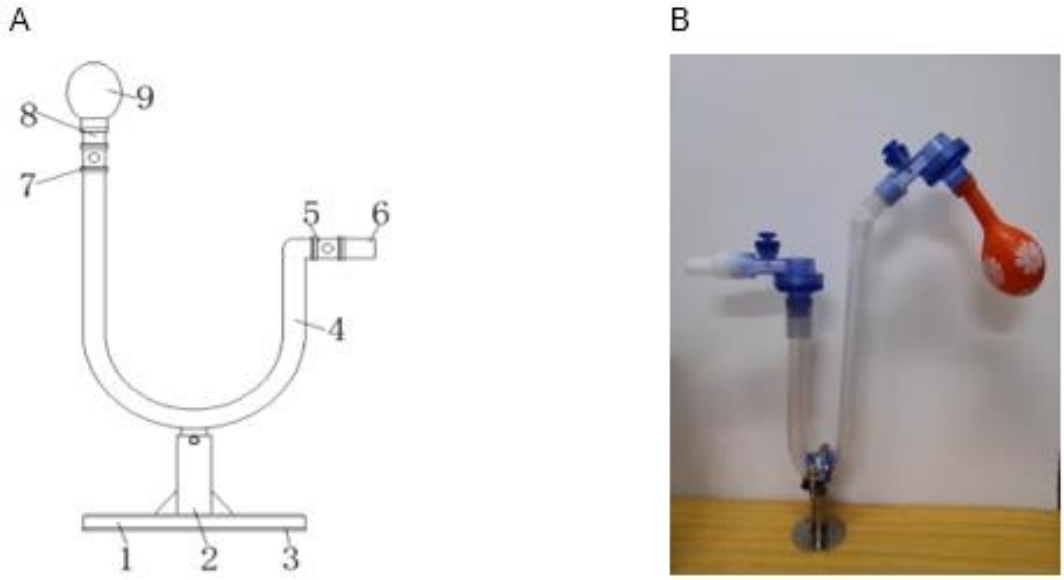

Figure 1. Schematic (A) and physical (B) diagrams of the portable lung function respiratory training device used in this study. 1, Base; 2, Lifting structure; 3, Anti-slip pad; 4, Transparent tube; 5, First valve; 6, Blowing mouthpiece; 7, Second valve; 8, Connecting tube; 9, Balloon; SSSSSSSS10, Fixing tube; 11, Limiting plate; 12, Extending rod; 13, Positioning groove; 14, Knob; 15, Threaded rod; 16, Tap water.

Technical Operation of the Device

Place the device on a tabletop. When adjusting the height, rotate the knob to adjust the height of the extending rod according to the user's needs. After adjusting the height, secure the knob, and open the first and second valves. The patient blows into the blowing mouthpiece, and the gas enters the transparent tube through the first valve, pushing the tap water. When a large volume of gas is blown in, the balloon expands, training lung capacity in this manner. To increase training difficulty, adjust the opening diameter of the first valve to change the volume of air entering the transparent tube. Simultaneously, reduce the amount of water in the transparent tube to increase resistance. To meet training standards, patients need to increase blowing force to enhance training intensity. Different resilience balloons can be used to increase balloon expansion difficulty and vary training intensity.

Subjects

This study adhered to the ethical standards of The Ethical Human Committee registration (code NO. HYLL-2024-021).

General Information

One hundred patients diagnosed with lung cancer between December 2022 and March 2023 at a hospital in Hainan Province, China, were randomly divided into two groups: 50 patients in the control group and 50 patients in the research group.

Inclusion Criteria

Clinically diagnosed with lung cancer confirmed by pathological examination, underwent surgical treatment; age over 60 years old; clear consciousness, stable condition; no postoperative lung infections; signed informed consent form.

Exclusion Criteria

Patients with concurrent malignant tumors; Patients unable to participate in respiratory training due to cognitive dysfunction, communication disorders, poor compliance, etc.; Three patients declined or withdrew consent during the procedure.

Control Group

Patients received routine postoperative care and were trained using traditional respiratory training methods, including diaphragmatic breathing, pursed-lip breathing, and blowing balloons, with each session lasting 15-20 minutes, twice daily. Diaphragmatic Breathing: Patients assumed a comfortable position such as supine, semi-recumbent, or semi-supine, with knees bent, allowing relaxation of the abdominal muscles. With hands placed on the abdomen, patients exhaled forcefully, inhaling through the nose and exhaling through the mouth, holding their breath for 3-5 seconds. The exhalation time was twice the inhalation time to ensure full lung expansion. Training duration was maintained for 5 minutes (Alaparthi *et al.,* 2016; Huang *et al.,* 2017). Pursed-Lip Breathing Training: Patients were instructed to exhale with their lips puckered, resembling whistling, to exhale as much air as possible. The frequency was slowed down, maintaining a ratio of inhalation to exhalation of 1:2 to prevent premature closure of small airways and accelerate the expulsion of residual gas from the lungs. Training duration was maintained for 5 minutes (Dellweg *et al.,* 2017). Balloon Blowing Technique: Patients performed two deep breaths, keeping the abdomen inflated while blowing into the balloon until it expanded. This exercise lasted 5 minutes per session.

Experimental group

Patients began respiratory muscle and pulmonary function rehabilitation training upon awakening from surgery, with sessions lasting 15-20 minutes, twice daily. Nurses introduced the use of the portable lung function respiratory training device, demonstrated its operation, provided instructions for device disinfection and replacement of disposable materials, and conducted postoperative respiratory training health education. Patients were guided to independently complete respiratory training exercises regularly, overcoming psychological barriers and resistance, and motivating active

participation and compliance to complete postoperative respiratory rehabilitation treatment in the hospital.

Portable Lung Function Respiratory Training Device Training Method: Patients lay flat or in a semi-recumbent position, with the device placed flat on a surface (such as a table or countertop), with the blowing mouthpiece facing the patient's mouth. Family members first filled the device with the highest marked water capacity, allowing the patient to blow slowly to inflate the balloon at the other end. Depending on the patient's condition, the water volume in the container was gradually reduced to increase resistance, allowing the patient to train blowing. The advantage of this device is its ability to increase resistance by adjusting the water volume in the container, from minimal to maximum resistance, to achieve progressively increasing training intensity for the patient. Training duration was controlled within 5 minutes.

Other traditional respiratory training methods, such as diaphragmatic breathing, pursed-lip breathing, and balloon blowing, were performed simultaneously with the control group.

Observation Indices

Comparison of lung function and respiratory muscle indices on the 3rd and 7th days of postoperative respiratory muscle rehabilitation training between the two groups, including the first-second forced expiratory volume (FEV1) and forced vital capacity (FVC).

Statistical Methods

Data were analyzed using SPSS 21 software. Normally distributed quantitative data were expressed as mean ± standard deviation, and intergroup comparisons were performed using t-tests. Non-normally distributed quantitative data were expressed as median (P25, P75), and intergroup comparisons were conducted using non-parametric rank-sum tests. A significance level of $P < 0.05$ was considered statistically significant.

Results

Comparison of General Information

A total of 100 patients who underwent lung surgery at our hospital from December 2022 to March 2023 were included in the study. Using the random number table method, patients were divided into two groups: the control group (50 cases) and the observation group (50 cases). In the control group, there were 35 males and 15 females, with an average age of (69.0 ± 4.5) years, ranging from 60 to 79 years. The observation group consisted of 34 males and 16 females, with an average age of (69.2 ± 4.3) years, ranging from 60 to 80 years. Both groups received routine surgical treatment, and there were no significant differences ($P > 0.05$) in terms of age, sex, disease type, and other general information, indicating clinical comparability.

Comparison of FVC and FEV1 between the Control Group and Test Group

a. On the 3rd day of postoperative respiratory muscle rehabilitation training, the FVC and FEV1 levels were compared between the two groups, and the differences were not statistically significant (FEV1: $t = 0.256$, $P = 0.754$, $P > 0.05$; FVC: $t = 0.198$, $P = 0.768$, $P > 0.05$).

b. On the 7th day of postoperative respiratory muscle rehabilitation training compared to the 3rd day, both the control group (FEV1: 1.89 ± 0.29, FVC: 2.35 ± 0.43) and the test group (FEV1: 2.07 ± 0.26, FVC: 2.07 ± 0.26) showed statistically significant increases in FVC and FEV1 levels compared to the 3rd day ($P < 0.05$).

c. On the 7th day of postoperative respiratory muscle rehabilitation training between the two groups, the FVC and FEV1 levels in the test group were higher than those in the control group, with a statistically significant difference (FEV1: $t = 2.235$, $P = 0.025$; FVC: $t = 2.401$, $P = 0.020$, $P < 0.05$).

Table 1 Comparison of lung function indices between the two groups

Group	num	FEV1		FVC	
		3rd	7th	3rd	7th
Control Group	50	1.67 ± 0.31	1.89 ± 0.29[a]	2.06 ± 0.31	2.35 ± 0.43[a]
Test group	50	1.63 ± 0.29	2.07 ± 0.26[a]	2.09 ± 0.40	2.07 ± 0.26[a]
t		0.256	2.235	0.198	2.401
p		0.754	0.025	0.768	0.020

Note: "a" indicates significance at $P < 0.05$ compared to the same group of treatment interventions. FEV1 represents the 1st-second expiratory volume, while FVC denotes forced vital capacity.

Discussion

Lung cancer is a highly prevalent and fatal malignancy, with surgical treatment being an effective approach. However, it can impact patients' postoperative respiratory function. Often, patients experience reduced tidal volume and increased respiratory rate due to pain, leading to incorrect breathing patterns. Consequently, this results in decreased functional residual capacity, causing symptoms such as airway closure, breathing difficulty, and reduced exercise capacity, thus affecting quality of life(Ban *et al.,* 2016). Respiratory difficulty is a common complication in lung cancer patients, necessitating regular respiratory exercises due to weakened respiratory muscles, which cause breathing difficulties and decreased exercise capacity. Beaumont,*et al.*2018 demonstrated that respiratory exercises (including cough training, diaphragmatic breathing, pursed-lip breathing, local respiratory training, systemic respiratory gymnastics, and respiratory training using various instruments) can alleviate respiratory difficulties. Additionally, two other studies revealed that respiratory training significantly alleviates respiratory difficulties, improves the 6-minute walk distance (6MWD) in lung cancer patients, enhances respiratory muscle contraction, reduces oxygen consumption, clears airway secretions, improves lung ventilation and gas exchange functions(Beaumont *et al.,*2018), and further promotes patient physical recovery(Kumar *et al.,* 2016; Wu *et al.,* 2018).

The pathogenesis of lung atelectasis involves neural compression, dysfunction or loss of surfactants, airway closure, or intermittent closure, resulting in limited oxygen absorption by alveoli (Wang *et al.,* 2019A). Meta-analysis reports on pneumonia subgroups analyzing studies on lung atelectasis have shown that postoperative respiratory rehabilitation training can reduce hospitalization time and significantly reduce the incidence of complications(Liu, 2019).

Respiratory rehabilitation training using a portable lung function respiratory training device can strengthen diaphragmatic breathing (Furlanetto & Pitta, 2017), maintain correct breathing patterns, prevent inadequate lung ventilation due to postoperative chest injury, enhance the activity of chest, abdominal, and diaphragmatic muscles, improve lung expansion and contraction function, and increase lung capacity (Wang *et al.,* 2019B). Diaphragmatic breathing training can simultaneously increase lung capacity, improve airway clearance function, and strengthen residual gas elimination (Hopper *et al.,* 2019; Ma *et al.,* 2017). Pursed-lip breathing can train respiratory muscle function, enhance respiratory muscle endurance, promote lung expansion, effectively improve lung ventilation and gas exchange dynamics, reduce functional residual volume in alveoli, strengthen chest movement training, improve chest and lung compliance, and enhance lung capacity, thereby promoting early lung re-expansion (Nguyen & Duong, 2019; Yang *et al.,* 2022).

The developed portable lung function respiratory training device is easy to operate, adds interest, enhances patient engagement, and improves patient compliance with rehabilitation training. Compared to traditional blowing balloon training methods, balloon blowing training can easily lead to hyperventilation syndrome during lung volume training due to excessive forceful and rapid inhalation and exhalation, which can cause respiratory alkalosis (Taverne *et al.,* 2021). Symptoms may include darkening of limbs and lips, chest tightness, rapid heartbeat, and even shortness of breath, drowsiness, or coma. Excessive forceful blowing can lead to congestion and edema of the airway mucosa (Abisha Olive, 2020). If personal hygiene is not observed during balloon blowing, it can lead

to infection by viruses, bacteria, and other pathogens, causing upper respiratory tract inflammation (Yuldashevich, 2024). The advantages of this device are: 1) Different levels of respiratory training resistance can be provided according to patient needs; 2) Different degrees of respiratory muscle training can be achieved based on water volume and balloon tension; 3) Convenient for clinical nursing staff to guide patients in use, addressing the inconvenience of bedridden patients during hospitalization and allowing rehabilitation training without changing patient posture; 4) Can be used as a simple lung capacity meter, calculating lung capacity based on a formula. The volume of a spherical balloon = 1/6 x C^3 / 3.142. (When measuring circumference in centimeters, the calculated volume is in milliliters). 5) Device accessories can be disassembled for high-temperature disinfection, and both the blowing mouthpiece and balloon use disposable materials, which can be replaced at any time, ensuring product cleanliness and hygiene. 6) Low cost and simple operation, allowing patients to continue respiratory training at home after discharge.

In the study, when comparing the results of the 7th postoperative respiratory muscle rehabilitation training with those of the 3rd session, both the control group (FEV1: 1.89±0.29, FVC: 2.35±0.43) and the test group (FEV1: 2.07±0.26, FVC: 2.07±0.26) showed statistically significant increases in FVC and FEV1 levels compared to the 3rd session ($P < 0.05$). This suggests that initiating respiratory rehabilitation training soon after surgery can effectively enhance the pulmonary function indices of lung cancer patients.

Furthermore, in the comparison between the two groups during the 7th postoperative respiratory muscle rehabilitation training, the test group exhibited significantly higher FVC and FEV1 levels than the control group, with statistical significance (FEV1: $t=2.235$, $P=0.025$; FVC: $t=2.401$, $P=0.020$, $P < 0.05$). This indicates that the use of the portable pulmonary function respiratory training device is more effective in enhancing the postoperative pulmonary function indices of lung cancer patients compared to traditional training methods.

Conclusion

In summary, the independently developed portable pulmonary function respiratory training device, when used for respiratory function exercises during postoperative care, effectively improves various respiratory and pulmonary function indices in patients, enhances pulmonary respiratory function, promotes postoperative pulmonary function recovery, and demonstrates good efficacy. So it can be concluded that this portable pulmonary function respiratory training gadget is more successful than standard training techniques in improving postoperative pulmonary function indices in lung cancer patients.

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Conflict of Interest:

There are no conflicts of interest.

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