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Effectiveness of Modified Flow-Oriented Incentive Spirometry Compared with Diaphragmatic Breathing Exercises in Tracheostomized Patients

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Abstract

Tracheostomy is frequently performed in critically ill patients, particularly in those requiring prolonged mechanical ventilation. Following tracheostomy, impaired cough effectiveness, reduced inspiratory volumes, retained secretions, and shallow breathing may contribute to impaired lung expansion and atelectasis. Incentive spirometry promotes sustained maximal inspiration and may facilitate lung expansion. However, evidence regarding its use in tracheostomized patients is limited. The primary objective of this study is to evaluate the effectiveness of modified flow-oriented incentive spirometry on arterial partial pressure of oxygen (PaO_2), and arterial partial pressure of carbon dioxide ($PaCO_2$) in tracheostomized patients and to compare its effects with diaphragmatic breathing exercises.

A comparative pretest-post-test study was conducted among 20 tracheostomized patients. Participants were allocated into an experimental group receiving modified flow-oriented incentive spirometry and a comparison group receiving diaphragmatic breathing exercises, with 10 participants in each group. The intervention was administered under physiotherapist supervision for 7 days. Both groups performed 10–15 breaths per session, three times a day. Outcome measures included PaO_2, and $PaCO_2$. Within-group changes were analyzed using the paired t test, while between-group differences were analyzed using the independent t test. Both groups showed significant improvements in PaO_2 and reductions in $PaCO_2$ following intervention ($p < 0.001$). However, the modified incentive spirometer group demonstrated significantly greater improvement in PaO_2 ($t = 2.197$, $p = 0.041$) and in $PaCO_2$ ($t = -2.571$, $p = 0.019$) compared with the diaphragmatic breathing group. The findings of this study suggest that modified flow-oriented incentive spirometry may be more effective than diaphragmatic breathing exercises alone in improving arterial blood-gas parameters in tracheostomized patients.

Keywords: Tracheostomy, incentive spirometry, inspiratory capacity, atelectasis, PaO_2, $PaCO_2$, diaphragmatic breathing.

1. Introduction

Tracheostomy is often performed in an intensive care patient when long-term ventilation (>7-10 days) is anticipated. Patients with tracheostomy may experience impaired cough effectiveness, retention of bronchial secretion, reduced lung volume and increased risk of pulmonary complications. Physiotherapy is usually required to optimize lung function in tracheostomized patients. Incentive spirometer is a simple technique designed to encourage slow, sustained maximal inspiration and promote lung expansion. By providing visual feedback it encourages the patients to inspire more volume of air and helps in lung expansion and clearance of secretions. However, conventional incentive spirometers are primarily designed for patients who breathe through the upper airway.

Any patient with tracheostomy tube in situ who requires chest physiotherapy, conventional incentive spirometry may require modification to establish an appropriate connection between the device and tracheostomy tube. Previous studies have described the use of a modified incentive spirometry in tracheostomy patients using a Y-connector, commonly used as an anesthesia tubing connector to facilitate the connection between the incentive spirometer and the tracheostomy tube. Such modifications allow the patient to perform inspiratory exercises through the tracheostomy [1].

In another study, Sachin Wali et al. used a T-piece connector, an elbow connector, and a reservoir bag with a one-way inspiratory valve to provide high-flow oxygen. During spirometer exercise, oxygen tubing is connected to the reservoir bag. Supplementing oxygen in critically ill patients improves exercise tolerance and reduces dyspnoea [2]. Bloria et al. proposed using a modified endotracheal tube as an adaptor [3]. Arasu et al. designed a modification using an elbow connector and a catheter mount with a double-swivel port [4]. No standardized adapter is currently available for connecting an incentive spirometer to a tracheostomy tube.

Patients with tracheostomy are at increased risk of hypoxemia and reduced pulmonary function [5]. This may result from decreased lung expansion, altered respiratory mechanics, excessive bronchial secretions, ineffective cough, and ventilation–perfusion mismatch, all of which can increase the risk of airway obstruction and impaired ventilation. Incentive spirometry encourages maximal lung expansion through the patient's inspiratory effort. Visual feedback from the device promotes sustained deep inspiration. Flow oriented incentive spirometry increases lung capacity, and pulmonary function [6,7].

2. Materials and Methods

A comparative pretest- posttest study was conducted among 20 tracheostomized patients admitted to the Medical Intensive Care Unit of Government Medical College Hospital, Tirupur, Tamil Nadu. A randomized comparative pretest-post-test study design was used. The study was conducted over a period of six months, from January 2026 to July 2026. Twenty participants were selected after obtaining informed consent and were allocated into two groups of 10 participants each: an experimental group that received modified flow-oriented incentive spirometry and a comparison group that received diaphragmatic breathing exercises.

Inclusion criteria:

1. Cooperative patients able to follow commands
2. Aged 18–55 years, of either sex
3. Extubated from mechanical ventilation and breathing spontaneously through T-piece
4. Patients who underwent tracheostomy following poisoning-related respiratory complications.**Exclusion criteria:**

1. Oxygen saturation (SpO_2) <90%
2. Respiratory rate >35 breaths/min

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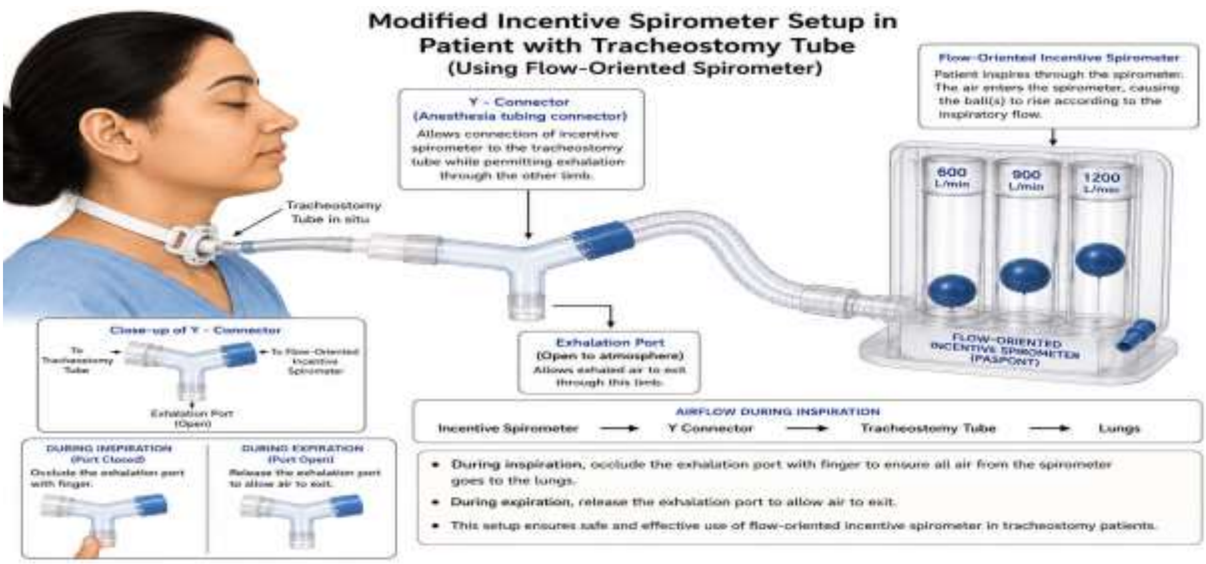
3. Patients unable to breathe spontaneously or require mechanical ventilation
4. Patients who are cardio vascularly unstable
5. Patients with lung injury or infectious diseases
6. Patients who are unable to tolerate upright sitting or semi-recumbent position.

Treatment method:

The experimental group received modified flow-oriented incentive spirometry under physiotherapist supervision. In this study, a Y-adapter with three ports was used. The main stem was connected to the tracheostomy tube, one arm to the incentive spirometer, and the other arm was left open as an expiratory pathway. The open port was occluded with a finger during inspiration and released during expiration. The joints were secured with micropore surgical tape to maintain an adequate connection during the intervention. A slow, sustained inspiratory effort was used to activate the flow-oriented incentive spirometer, as indicated by the rising indicator ball. The breathing pattern while using the incentive spirometer is important; lower chest expansion should be emphasized. Participants performed 10–15 slow, sustained inspiratory efforts using the modified flow-oriented incentive spirometer during each session and were instructed to perform the exercise three times a day.



The comparison group received diaphragmatic breathing exercises (breathing control) for the same period. For breathing control, the patient was positioned comfortably with one hand on the upper abdomen and encouraged to inhale through the nose, allowing movement of the lower chest and abdomen. The hand should rise and move outward during inspiration. The upper chest and shoulders should remain relaxed, and expiration should be relaxed and passive.

Outcome measures:

Baseline assessments were performed before the intervention, and post-intervention assessments were conducted after seven days. The outcome measures included arterial partial pressure of oxygen (PaO_2), and arterial partial pressure of carbon dioxide ($PaCO_2$). These measurements provide essential information about the patients' respiratory and metabolic status.

Normal value (arterial blood);

PaO_2: 80–100 mmHg; $PaCO_2$: 35–45 mmHg

PaO_2 reflects the efficiency of oxygen transfer from the lungs into the blood. $PaCO_2$ reflects the adequacy of alveolar ventilation. Shallow ventilation can result in inadequate carbon dioxide elimination and increase in $PaCO_2$. Improved alveolar ventilation can improve PaO_2 and increased $PaCO_2$ elimination and a reduction in $PaCO_2$. Therefore, measuring PaO_2 and $PaCO_2$ before and after intervention can be used to evaluate the physiological effectiveness of breathing exercises in tracheostomy patients.
Within-group pretest and posttest differences were analyzed using the paired t test, while differences between the two groups were analyzed using the independent t test.
Twenty participants completed the study, with 10 participants in each group.

3. Results

The arterial blood gas parameters, PaO_2 and $PaCO_2$, were assessed before and after intervention in both groups. In the incentive spirometer group ($n = 10$), the mean PaO_2 increased from 72.9 ± 8.21 mmHg at pretest to 81.4 ± 7.57 mmHg at posttest, with a mean increase of 8.5 mmHg. The mean $PaCO_2$ decreased from 53.9 ± 5.28 mmHg to 45.3 ± 4.06 mmHg, with a mean reduction of 8.6 mmHg.
In the diaphragmatic breathing group ($n = 10$), the mean PaO_2 increased from 76.0 ± 5.94 mmHg at pretest to 82.0 ± 6.67 mmHg at posttest, with a mean increase of 6.0 mmHg. The mean $PaCO_2$ decreased from 50.9 ± 3.81 mmHg to 45.2 ± 4.10 mmHg, with a mean reduction of 5.7 mmHg.
Within-group analysis demonstrated statistically significant pretest-to-posttest changes in both PaO_2 and $PaCO_2$ in the incentive spirometer group (PaO_2: $t = 8.295$, $p < 0.001$; $PaCO_2$: $t = -8.988$, $p < 0.001$) and in the diaphragmatic breathing group (PaO_2: $t = 12.136$, $p < 0.001$; $PaCO_2$: $t = -9.544$, $p < 0.001$).
Following the intervention, PaO_2 improved significantly, with normalization of the previously elevated $PaCO_2$ level. This indicates that both incentive spirometry and diaphragmatic breathing exercises improved lung expansion and alveolar ventilation.
Comparison of the mean changes between the two groups showed a statistically significant difference in PaO_2 improvement ($t = 2.197$, $p = 0.041$) and $PaCO_2$ reduction ($t = -2.571$, $p = 0.019$), with greater improvement observed in the incentive spirometer group. These findings indicate that both interventions improved arterial blood gas parameters, with modified incentive spirometry producing a greater overall change in PaO_2 and $PaCO_2$.

4. Discussion

Respiratory failure develops when the rate of gas exchange between the air and the blood fails to match the body’s metabolic demands. The patient therefore loses the ability to provide adequate oxygen (O_2) to the blood and develops hypoxemia, or the patient is unable to ventilate adequately and develops hypercapnia.
The present study found that both modified incentive spirometry and diaphragmatic breathing exercises produced favorable changes in arterial blood gas parameters among patients with tracheostomy.
However, the modified incentive spirometry group showed a significantly greater improvement in PaO_2 and $PaCO_2$ compared with the diaphragmatic breathing group. Similar effects of respiratory exercises on arterial blood gas parameters have been reported previously [8].
The improvement observed with modified incentive spirometry may be attributed to repeated slow and deep inspiratory efforts, which can promote lung expansion and improve ventilation. The visual feedback provided by the device may also encourage active participation and consistent performance of the exercise

[9]. Diaphragmatic breathing also demonstrated beneficial changes, suggesting that it remains a useful respiratory intervention.

5. Conclusion

Both modified flow-oriented incentive spirometry and diaphragmatic breathing exercises were associated with significant improvements in PaO_2 and reductions in $PaCO_2$ in tracheostomized patients. However, the modified incentive spirometry group demonstrated significantly greater improvements in both parameters compared with the diaphragmatic breathing group. These findings suggest that modified flow-oriented incentive spirometry may provide an additional benefit in improving arterial blood-gas parameters in tracheostomized patients. Further studies with larger sample sizes are needed to confirm these findings and establish their clinical applicability.

6. Limitations

1. The modified incentive spirometer setup bypassed the normal upper airway mechanisms of filtering and humidification of inspired air,
2. The additional connector and incentive spirometry tubing may increase airflow resistance and may increase the work of breathing.
3. The small sample size may limit the generalizability of the study findings.

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