# Hyperinflation using pressure support ventilation improves secretion clearance and respiratory mechanics in ventilated patients with pulmonary infection: a randomised crossover trial

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**Question**: Is ventilator-induced hyperinflation in sidelying more effective than sidelying alone in removing secretions and improving respiratory mechanics in ventilated patients with pulmonary infection? **Design**: Randomised crossover trial with concealed allocation and intention-to-treat analysis. **Participants**: 30 mechanically ventilated patients with pulmonary infection in an adult intensive care unit. **Intervention**: The experimental intervention was 30 minutes of ventilator-induced hyperinflation using pressure support ventilation in sidelying; the control intervention was 30 minutes of sidelying. Participants received both interventions on the same day, with a five-hour washout period between them. **Outcome measures**: Secretion clearance was measured as sputum volume retrieved during the intervention. Respiratory mechanics were measured as static compliance and total resistance of the respiratory system before and after the intervention. **Results**: The experimental intervention cleared 1.3 ml (95% CI 0.5 to 2.2) more secretions than the control. After ventilator-induced hyperinflation in sidelying, respiratory compliance had increased 4.7 ml/cm$H_2O$ (95% CI 2.6 to 6.8) more than in sidelying alone. There was no difference in total resistance of the respiratory system between the interventions (mean difference 0.3 cm$H_2O$/l/s, 95% CI –0.8 to 1.3). **Conclusion**: The application of hyperinflation using pressure support ventilation in mechanically ventilated patients with pulmonary infection improves secretion clearance and increases static compliance of the respiratory system. **[Lemes DA, Zin WA, Guimarães FS (2009) Hyperinflation using pressure support ventilation improves secretion clearance and respiratory mechanics in ventilated patients with pulmonary infection: a randomised crossover trial. *Australian Journal of Physiotherapy* 55: 249–254]**

**Key words:** Randomized controlled trial, physiotherapy, intensive care, pulmonary ventilator, respiratory mechanics

## Introduction

In mechanically-ventilated patients, augmented mucus production and impaired mucociliary clearance are common characteristics that lead to an increased risk of mucus retention in the airways as well as to the development of pulmonary infection and obstructive atelectasis (Konrad et al 1994). Therefore, respiratory physiotherapy intervention (positioning, postural drainage, percussion, vibration, endotracheal suctioning, and manual hyperinflation) is used routinely in the management of ventilated patients in the intensive care unit to prevent mucus retention and pulmonary complications, improve oxygenation, and re-expand collapsed areas (Clini and Ambrosino 2005).

The use of positive pressure devices has been part of physiotherapy intervention since intermittent positive pressure breathing was introduced in clinical practice (Motley and Werko 1947). In intensive care settings, the use of positive pressure by physiotherapists includes manual hyperinflation (bagging or bag squeezing), which has been shown to increase oxygenation and mobilise excessive bronchial secretions, and to reinflate collapsed areas (Berney and Denehy 2002, Berney et al 2004, Choi and Jones 2005, Hodgson et al 2007, Blattner et al 2008). It involves the application of a slow, deep inspiration using a manual resuscitation bag applied to the endotracheal or tracheostomy tube, followed by an inspiratory pause (1–2 seconds), and a rapid release of the resuscitation bag, combined with thoracic vibration, to improve expiratory flow and stimulate a cough (Clement and Hubsch 1968). An alternative method of performing pulmonary hyperinflation uses the mechanical ventilator. Although there is evidence that positive pressure interventions such as continuous positive airway pressure and intermittent positive pressure breathing can improve lung expansion and mobilise secretions in the airway (Denehy and Berney 2001), there are few studies examining ventilator-induced hyperinflation as a physiotherapy intervention in intensive care (Berney and Denehy 2002, Berney and Denehy 2003, Savian et al 2006). To our knowledge, there are no studies investigating secretion clearance and respiratory mechanics in patients undergoing hyperinflation using pressure support ventilation. The use of pressure support ventilation to achieve hyperinflation may be beneficial, since it is comfortable for the patient and the pressure limit avoids excessive pressures. Therefore, the research question for this study was:

> Is ventilator-induced hyperinflation using pressure support ventilation in sidelying more effective than sidelying alone in removing secretions and improving respiratory mechanics in ventilated patients with pulmonary infection?

## Method

### Design

This was a randomised, crossover trial in which patients were their own control. Participants were recruited from patients admitted to an 11-bed intensive care unit at a tertiary referral hospital. The allocation sequence was prepared by an investigator who was not involved in recruitment, intervention, or measurement. Randomisation was computer generated in 3 blocks of 10 and stored in sealed, opaque envelopes that were opened by the physiotherapist delivering the intervention on the day. The experimental intervention was 30 minutes of ventilator-induced hyperinflation using pressure support ventilation in sidelying and the control intervention was 30 minutes of sidelying. All participants received both interventions on the same day, with a five-hour washout period between them. Secretion clearance was measured during both interventions while respiratory mechanics were measured before and after (Figure 1). The same physiotherapist, who was not blinded to intervention allocation, delivered both interventions and recorded all measurements.

### Participants

Mechanically ventilated patients were included if they had a medical diagnosis of pulmonary infection (defined according to laboratory and radiological criteria) and hypersecretion (defined as the interval between tracheal suctioning < 2 hours). All participants were initiating all breaths spontaneously. They were excluded if they had haemodynamic instability (defined as a heart rate > 130 bpm and mean arterial pressure < 60 mmHg), used vasopressor drugs, had acute bronchospasm, had acute respiratory distress syndrome, had atelectasis (identified by an independent radiologist), were immediately post neurosurgery, had an untreated pneumothorax, had lung haemorrhage, or were unable to be positioned in sidelying.

### Intervention

The experimental intervention consisted of 30 minutes of ventilator-induced hyperinflation in sidelying. Initially, participants were mechanically ventilated in the volume-induced mode, with a tidal volume of 8 ml per kilogram of body weight, inspiratory flow of 60 litres per minute (square wave), with hyperinflated cuff, positioned in a supine 30-degree head-up position, and underwent tracheal aspiration. Inspiratory oxygen fraction and positive end-expiratory pressure remained unchanged. Next, they underwent 3 sighs with a two-fold increase in tidal volume (Mead and Collier 1959). Participants were then positioned in sidelying with the more affected lung, verified on chest X-ray, uppermost. The mechanical ventilation was changed to the pressure support mode with a peak pressure of 40 $cmH_2O$ to apply hyperinflation. After 30 minutes, ventilation was returned to the original settings, participants were repositioned in the supine 30-degree head-up position and underwent tracheal aspiration and another 3 sighs with a two-fold increase in tidal volume.

Physiological parameters (heart rate, mean arterial pressure, oxygenation, airway pressures, tidal volume, and respiratory rate) were recorded before, during, and after the experimental intervention to assess safety. Mean arterial pressure in mmHg, heart rate in bpm, and oxygenation were collected using a multiparameter monitor[a]. Tidal volume in ml and respiratory rate in bpm were collected from the ventilator display[b] and used to calculate minute ventilation. Mean, plateau, and peak airway pressures in $cmH_2O$ were also collected from the ventilator display. Adverse events were defined as heart rate > 140 bpm, mean arterial pressure < 60 mmHg, and/or arterial oxygen saturation < 90%.

The control intervention consisted of 30 minutes of sidelying without ventilator-induced hyperinflation or any other physiotherapy intervention.

### Outcome measures

The primary outcome was secretion clearance and secondary outcomes were respiratory mechanics. Secretion clearance was measured as sputum volume in ml. At the 15$^{th}$ and 30$^{th}$ minutes, the patients underwent artificial airway suctioning and secretions were collected in a sputum trap attached to the closed suction system. Then, sterile saline solution was flushed through the suction tubing into the trap to remove any secretions remaining in the catheter. The volume of sputum was calculated by summing the two measures and subtracting the volume of the sterile saline.

Respiratory mechanics were measured as static compliance and total resistance of the respiratory system. Tidal volume in ml, respiratory rate in bpm, and plateau, peak and mean airway pressures in $cmH_2O$ were collected from the ventilator display and used to calculate static compliance in $ml/cmH_2O$ and total resistance in $cmH_2O/l/s$ of the respiratory system. According to the interrupter technique (Bates et al 1985), a 2 s inspiratory pause (Lucangelo et al 2005) was applied and waveforms were examined to ensure a flat plateau for reliable measurements. The mean of five readings was used as the representative value for each variable.

### Data analysis

According to Hodgson et al (2000), power calculation indicated that 20 participants would provide sufficient power (80%) to detect a difference of 57% in sputum volume, assuming a standard deviation of 62% and significance of 0.05. Results are expressed as mean (SD), mean (SD) differences within interventions and mean differences (95% CI) between interventions. Two-way repeated-measures analysis of variance was used to examine the statistical significance of between-group differences in respiratory mechanics. Paired t-test was used to examine the statistical significance of between-group differences in sputum volume. Changes in haemodynamics, oxygenation, ventilation and airway pressures were examined using descriptive statistics. The significance level was set at $p = 0.05$.

## Results

### Flow of participants, therapists, centres through the trial

Recruitment and data collection were carried out between April 2006 and July 2007. Thirty mechanically ventilated patients, with medical diagnosis of pulmonary infection participated. All participants received both interventions and completed all measurements (Figure 1). Participants' characteristics are given in Table 1. The participants were similar in terms of respiratory mechanics before intervention (Table 2).

A single physiotherapist with 10 years experience in critical care settings delivered both the experimental and control interventions.