# A comparison of the effects of manual and ventilator hyperinflation on static lung compliance and sputum production in intubated and ventilated intensive care patients

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ABSTRACT **Background and Purpose**. *Lung hyperinflation is a technique used by physiotherapists to mobilize and remove excess bronchial secretions, reinflate areas of pulmonary collapse and improve oxygenation. Hyperinflation may be delivered by the ventilator or manually, by use of a manual resuscitation circuit, depending upon the respiratory and cardiovascular status of the patient. The effects of manual hyperinflation, with respect to excess bronchial secretions and static lung compliance, have been well-established. There is, however, only limited evidence as to the efficacy of ventilator hyperinflation as a physiotherapy treatment technique. The purpose of the present study was to compare the effects of manual hyperinflation and ventilator hyperinflation on static pulmonary compliance and sputum clearance in stable intubated and ventilated patients.* **Method**. *Twenty patients who met the inclusion criteria were studied. This was a double crossover study where all patients were randomly allocated to one of two treatment sequences over two days. The first sequence involved manual hyperinflation followed two hours later by ventilator hyperinflation and the order was reversed on the second day. In the second sequence, ventilator hyperinflation preceded manual hyperinflation. The variables of static pulmonary compliance and sputum wet weight were analysed by use of an analysis of variance (ANOVA) for repeated measures. Statistical significance was set at* $p < 0.05$. **Results**. *There was no significant difference in sputum wet weight production between either technique or on either day of treatment. Static pulmonary compliance improved with both hyperinflation techniques (*$p < 0.05$*).* **Conclusions**. *Hyperinflation as part of a physiotherapy treatment can be performed with equal benefit using either a manual resuscitation circuit or a ventilator. Both methods of hyperinflation improve static pulmonary compliance and clear similar volumes of pulmonary secretions.*

**Key words**: lung hyperinflation, sputum wet weight, static pulmonary compliance

## INTRODUCTION

Atelectasis is common in intubated and ventilated patients (Johnson et al., 1987). The reasons for this are multifactorial and include low volume ventilation strategies. It has been suggested that the use of intermittent large tidal volume inflations of the lungs may help prevent the development of atelectasis (Bendixen et al., 1963; Suter et al., 1978; Blanch et al., 1994; Dorrington and Radcliffe, 1999; Pelosi et al., 1999).

Manual hyperinflation involves delivering tidal volumes to airway pressures of 40 cm $H_2O$ (Rothen et al., 1993) or a tidal volume ($V_T$) that is 50% greater than that delivered by the ventilator (Singer et al., 1994). This is followed by a quick release of pressure on expiration, leading to a rapid flow of air, simulating the effect of a cough (Clement and Hubsch, 1968). Physiotherapists have used manual hyperinflation for many years for mobilizing excess pulmonary secretions, reinflating areas of atelectasis and improving oxygenation (Stiller et al., 1990; Tweed et al., 1993; Webber and Pryor, 1993; Singer et al., 1994; Stiller et al., 1996). It can be delivered using an anaesthetic circuit or the ventilator.

The short-term effects of manual hyperinflation on pulmonary compliance and resolution of atelectasis have been well documented (Marini et al., 1979; Rhodes, 1987; Stiller et al., 1990; Jones et al., 1992; Rothen et al., 1993; Stiller et al., 1996; Hodgson et al., 2000). However, manual hyperinflation is contraindicated in several patient groups who may otherwise benefit from the technique. These patients may require higher levels of positive end expiratory pressure (PEEP) or may be agitated and intolerant of manipulation of their endotracheal tube. Ventilator hyperinflation is achieved by altering the ventilatory settings to gradually increase tidal volume (Imle and Klemic, 1989). It may produce the same effects as manual hyperinflation whilst maintaining the PEEP level and controlling airway pressure limits (Brown et al., 1987; Imle and Klemic, 1989). There is, however, no evidence as to the efficacy of ventilator hyperinflation as a physiotherapy treatment technique. As there are no controlled trials comparing the technique to manual hyperinflation, the clinical use of ventilator hyperinflation is not widespread. Therefore, the purpose of the present study was to compare the effects of manual hyperinflation and ventilator hyperinflation on static lung compliance and sputum wet weight in stable intubated and ventilated patients.

## METHOD

This was a prospective, randomized, controlled crossover study of patients who were intubated, ventilated and cardiovascularly stable.

### Subjects

The study was approved by the Ethics and Human Research Committee at the Austin and Repatriation Medical Centre (ARMC), and informed consent was obtained from the next of kin and from the treating intensive care physician. Sample size calculation was based on sputum wet weight using the mean difference and standard deviation from Hodgson et al. (2000). For the given effect size, alpha = 0.05 (two-tailed) and power of 0.8, the sample size estimate was 20 subjects.

Subjects were included if they were:

- Intubated and ventilated.
- Would normally receive hyperinflation as a part of their physiotherapy treatment.

Patients were excluded from the trial if they:

- Required a fraction of inspired oxygen ($FiO_2$) ≥ 0.6.
- Had a PEEP ≥ 10 cm $H_2O$.
- Had pulmonary pathology where lung hyperinflation was contraindicated (for example, adult respiratory distress syndrome, exacerbation of chronic obstructive pulmonary disease).
- Were prescribed a head-up position for brain disease.
- Had an unstable cardiovascular condition as defined by a mean arterial pressure (MAP) ≤ 75 mmHg with a fluctuation of 15 mmHg with position change, a heart rate >130.
- Had an arterial oxygen saturation ($SaO_2$) ≤ 90%.

Patients were withdrawn from the study if they suffered cardiovascular compromise during the treatment, as defined by the above variables.

## Procedure

All subjects were randomly allocated using sealed envelopes to a treatment sequence A or B on Day 1. Patients received two treatments, at least two hours apart, on two consecutive days. The first treatment was given in the morning and the alternate treatment was performed in the afternoon. On Day 2 the order of the treatments was reversed using the same patient position sequence (Figure 1).

Treatment A consisted of gravity assisted drainage with the foot of the bed elevated to 35°–45° from the horizontal, six sets of six manual hyperinflation breaths and endotracheal suctioning. Treatment B consisted of the same treatment except that ventilator hyperinflation was used instead of manual hyperinflation. The initial treatment position of the subject was decided upon by consultation between the intensive care physician and treating physiotherapist.

Subjects were turned into the appropriate sidelying position and left undisturbed for 10 minutes before treatment. The foot of the bed was then elevated and treatment started. One researcher, blinded to all outcome measures, performed all hyperinflation treatments. An assistant physiotherapist collected sputum and recorded all measurements. It was not possible for the second physiotherapist to be blinded as the assistant physiotherapists were assisting in the treatment of the patient.

### *Manual hyperinflation*

Manual hyperinflation breaths were delivered using a Mapleson C anaesthetic circuit using a 10 l/min fresh gas flow (Ohmeda

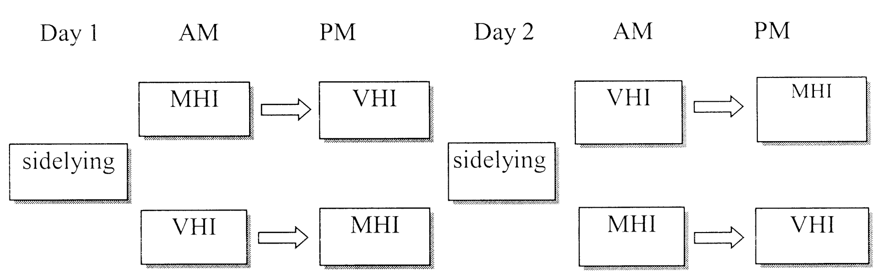


FIGURE 1: Flowchart of the treatment procedure: MHI = manual hyperinflation; VHI = ventilator hyperinflation.

MA 105). These breaths had a slow inspiration for 3 s duration to a peak airway pressure of 40 cm $H_2O$, as measured by an inline manometer (Bird pressure manometer, Tag Medical). A 2-s end inspiratory pause was followed by an uninterrupted expiration during which the bag was held compressed. The manual hyperinflation treatment consisted of six sets of six hyperinflation breaths, each set being followed by six tidal breaths to a peak airway pressure of 20 cm $H_2O$. The manual hyperinflation treatment was of 20 minutes duration.

*Ventilator hyperinflation*

In volume control, ventilators were set to six breaths per minute, an inspiratory flow of 20 l/min, incorporating a square wave form and a 2-s end inspiratory pause. Tidal volume was increased in 200 ml increments until a peak airway pressure of 40 cm $H_2O$ was achieved. Once this pressure was reached, six mechanical breaths were delivered to the patient. After this, the ventilator was reset to pre-treatment variables and the patient rested for 30 s. The sequence was then repeated. The treatment lasted 20 minutes and consisted of six sets of six ventilator hyperinflation breaths.

Endotracheal suction was performed using size 12 Baxter catheters (Baxter Health Care Corporation, Edward Critical Care Division, Irvine, CA 92714–5686, USA). The same catheter was used for each suction pass. The patients were suctioned three times throughout the procedure following every second set of hyperinflation breaths. Four millilitres of normal saline was used for lavaging down the endotracheal tube and 1 ml was used to wash through the suction catheter at the end of the treatment. An arterial line, ECG and pulse oxymetry were used to monitor the subject continuously (Hewlett Packard monitoring systems M1046-9001b, HP GmBH, Boedhingn, Germany).

## Measurement

*Sputum*

Once subjects were initially turned into the appropriate flat sidelying position they were suctioned once, and the sputum was discarded as it was thought to be related to positional change rather than the treatment. In order to measure the wet weight of sputum suctioned, the secretions were collected in a disposable sputum trap (40 cc specimen trap, Sherwood Medical, St Louis, MO 63103, USA; model no. 8884–724500). This was weighed before and after the treatment with a digital weighing scale (PC400, Hewlett Packard, Boedhingn, Germany). Before each measurement the scale was calibrated according to manufacturer's guidelines.

*Static pulmonary compliance*

After 10 minutes' rest before raising the foot of the bed, baseline measures of static pulmonary compliance were recorded. Once the treatment was completed subjects were returned to the horizontal sidelying position and remained there for up to two hours in accordance with their pressure care schedules. Measurements of static pulmonary compliance were recorded immediately and 30 minutes after treatment. All measures were performed with subjects in a flat sidelying position.

Static lung compliance was calculated by use of the formula $V_T$ / IP – PEEP, where $V_T$ is tidal volume, IP is inspiratory pressure and PEEP is positive end expiratory pressure (Nunn, 1993). The exhaled tidal volumes, end inspiratory plateau pressure and PEEP were read from the display on the ventilator by the assistant physiotherapist. Three readings of static pulmonary compliance were taken, end inspiratory plateau pressure was achieved using a 1.5 s pause at end inspiration which was programmed into the ventilator. The ventilators used were either the Bear 1000 (Bear) or the Bennetts Star Ventilator (Bennetts).

**Data management**

The sputum wet weight produced during manual hyperinflation and ventilator hyperinflation on each day of measurement was added to give a total value of sputum wet weight for each of the techniques. These values were then used for comparisons of sputum wet weight for the two techniques by use of a one-way ANOVA. The data for static pulmonary compliance was combined over the two days of measurement giving a mean value for manual hyperinflation and ventilator hyperinflation at each time point. These variables were analysed by use of an ANOVA for repeated measures. Probability values of $p < 0.05$ were deemed to be significant. Data is expressed as mean (95% confidence interval).

## RESULTS

Seventeen males and three females fulfilled the criteria for inclusion in the study. No subjectsts were withdrawn. The mean age of the subjects was 45.2 years (range 16–86 years). All subjects were intubated and mechanically ventilated with a mean $FiO_2$ of 0.44 (range 0.3–0.6). The descriptive data for subjects are presented in Table 1.

There was no significant difference in the sputum wet weight between treatments ($p = 0.11$) (Table 2). The mean difference in sputum production and 95% confidence interval was 2.65 grams (range 1.79–3.54). Both hyperinflation techniques significantly improved static pulmonary compliance ($p < 0.001$) (Table 3). Manual hyperinflation produced an average of 11.47% and 9.75% improvement in static pulmonary compliance immediately and 30 minutes post-treatment and ventilator hyperinflation produced a 9.8% and a 11.58% increase at the same time intervals.

There were no adverse changes in MAP, heart rate or $SaO_2$ nor was there an increase in inotropic support during any treatment over the two days of measurement.

## DISCUSSION

Physiotherapists use manual hyperinflation for the treatment and prevention of atelectasis and the mobilization of secretions (Rothen et al., 1993; Tweed et al., 1993; Webber and Pryor, 1993; Singer et al., 1994; Stiller et al., 1996; Hodgson et al., 2000). Although manual hyperinflation has been shown to be an effective technique in the management of intubated patients it has several limitations. These include disconnection of the patient from the ventilator resulting in loss of PEEP, poor control of airway pressure and flow and the fraction of inspired oxygen being 1.0 (Ciesla, 1996; Clarke et al., 1999). These limitations are eliminated with ventilator hyperinflation. We found that hyperinflation using the ventilator is as effective as manual hyperinflation in clearing excess pulmonary secretions and improving static pulmonary compliance.

Ten of the subjects were acute quadriplegic patients. However, it was not felt that this influenced the results of the present study, as there is no evidence that these patients respond differently from others to physiotherapy treatment. A crossover design was used to control for the effect of time of day of treatment, and

TABLE 1: Subject data

| *Subject/sex* | | *Age (years)* | *Diagnosis* | *CXR* | *$PaO_2/FiO_2$* | *APACHE II* | *Outcome* |
|---|---|---|---|---|---|---|---|
| 1 | m | 86 | Resp failure | LLL coll | 400.0 | 19 | Died |
| 2 | f | 18 | C5 quad | NAD | 467.3 | 10 | Survived |
| 3 | f | 33 | Guillain-Barré | RLL coll | 372.5 | 12 | Survived |
| 4 | m | 79 | Sepis/pneum | Ling/LLL cons<br>RLL coll | 460.0 | 22 | Survived |
| 5 | m | 77 | Total gastrectomy | LLL coll | 210.0 | 22 | Survived |
| 6 | m | 38 | C5 quad | LLL/LML coll<br>RUL cons | 247.5 | 14 | Survived |
| 7 | m | 74 | C sp fusion | LLL coll | 365.0 | 14 | Survived |
| 8 | m | 57 | C1 fusion | RML/RLL coll | 277.5 | 12 | Survived |
| 9 | m | 39 | C4 quad | NAD | 292.5 | 12 | Survived |
| 10 | m | 16 | C6 quad | LLL coll | 295.8 | 10 | Survived |
| 11 | m | 32 | C1 quad | RLL cons | 375.0 | 10 | Survived |
| 12 | m | 61 | C5 quad | RUL cons<br>LLL cons | 256.0 | 14 | Survived |
| 13 | m | 48 | C1 quad | RLL coll<br>LLL coll | 287.5 | 12 | Survived |
| 14 | m | 20 | C5 quad | RUL coll | 235.0 | 14 | Survived |
| 15 | m | 42 | Multi-trauma | LLL/LUL cons<br>RLL cons | 118.0 | 16 | Survived |
| 16 | f | 42 | Multi-trauma | LLL coll<br>RLL cons | 197.5 | 16 | Survived |
| 17 | m | 41 | C4 quad | LLL coll | 200.0 | 12 | Survived |
| 18 | m | 19 | Multi-trauma | RUL col<br>LUL coll<br>Ling cons | 230.0 | 14 | Survived |
| 19 | m | 39 | C5 quad | LLL/LML cons<br>RUL coll | 144.0 | 12 | Survived |
| 20 | m | 43 | Multi-trauma | LLL coll | 353.5 | 10 | Survived |

m = male; f = female; quad = quadraplegic; resp = respiratory; pnuem = pneumonia; C sp = cervial spine; coll = collapse; cons = consolidation; NAD = no abnormality detected; LLL = left lower lobe; LUL = left upper lobe; LML = left middle lobe; RLL = right lower lobe; RUL = right upper lobe; RML = right middle lobe; ling = lingula.

TABLE 2: Mean sputum production (95% confidence interval) for the two days of physiotherapy and the mean total sputum wet weight (95% confidence interval)

| *Day* | *Mean hyperinflation (g)* | *Ventilator hyperinflation (g)* |
|---|---|---|
| 1 | 6.87 (5.60–8.11) | 5.41 (414–6.68) |
| 2 | 6.18 (4.83–7.53) | 6.62 (5.38–7.86) |
| Mean (CI) | 6.53 95.86–7.20) | 6.01 (4.83–7.19) |

TABLE 3: Means (mean percentage improvement) (95% confidence interval)in static pulmonary compliance before and after physiotherapy

| *Hyperinflation* | *Pre-treatment (ml/cm $H_2O$)* | *Post-treatment (ml/cm $H_2O$)* | *30 min post-treatment (ml/cm $H_2O$)* |
|---|---|---|---|
| Manual | 46.2<br>(41.5–50.9) | 51.5 (11.5%)<br>(46.6–56.4) | 50.7 (9.7%)<br>(46.5–54.9) |
| Ventilator | 44.9<br>(40.5–49.3) | 49.3 (9.8%)<br>(45.7–52.9) | 50.1 (11.6%)<br>(45.5–54.7) |

also to perform four treatments on one day was impractical.

Static lung compliance and sputum wet weight were used as outcome measures to evaluate the efficacy of physiotherapy treatment. These short-term outcome measurements have been used in previous studies (Jones et al., 1992; Hodgson et al., 2000) and were chosen because they reflect physiological changes in patients in intensive care who are immobilized and intubated. These patients may have a reduction in pulmonary compliance due to mechanical ventilation (Oh, 1988), increased mucous production (Jones et al., 1997) and impaired mucociliary clearance mechanisms (Konrad et al., 1994). These factors have been associated with an increased risk of sputum retention, atelectasis and pneumonia (Anderson and Jenkins, 1993; Konrad et al.,1994). Both dry and wet weights of sputum have been previously used to assess the outcome of physiotherapy intervention. It has been suggested that the wet weight may be influenced by the presence of saliva (Rossman et al., 1982). The measurement of dried sputum weight may eliminate this problem. There is, however, no evidence for reliability of specific drying protocols in the literature. In addition, a recent study reported a strong linear relationship between the wet and dry weight of sputum (Cecins et al., 1999). For these reasons and because the subjects were intubated patients in whom the contamination of sputum with saliva was minimized, it was decided to use sputum wet weight as the outcome measure.

The aim of lung hyperinflation is to re-expand atelectasis (Stiller et al., 1990; Stiller et al., 1996), mobilize secretions (Hodgson et al., 2000) and prevent or reduce the incidence of nosocomial pneumonia in intubated patients. Currently, there is only limited evidence with regard to the effectiveness of physiotherapy treatment in the prevention of nosocomial pneumonia. In a previous study of manual hyperinflation twice as many patients in the control group (no manual hyperinflation) developed nosocomial pneumonia (Ntoumenoupolous et al., 1988). Although this result did not reach statistical significance, it was an important clinical finding.

Atelectasis is a common clinical problem in the intubated and ventilated patient (Oh, 1988; Jones 1997) and, if prolonged, may lead to hypoxaemia, pulmonary infection and fibrosis (Marini et al., 1979). In addition, loss of lung volume and atelectasis lead to a progressive reduction in pulmonary compliance making ventilation more difficult (Oh, 1988).

Recruitment manoeuvres such as hyperinflation have been shown to improve both atelectasis (Scholten et al., 1985; Stiller et al., 1990; Rothen et al., 1993; Tweed et al.,

1993) and static pulmonary compliance (Jones et al., 1992; Hodgson et al., 2000). The results of the present study were consistent with previous findings showing an improvement in static pulmonary compliance with both forms of hyperinflation (Jones et al., 1992; Hodgson et al., 2000). This is the first study to examine the effects of ventilator hyperinflation on static pulmonary compliance.

Although no cardiovascular changes were observed in the current study, manual hyperinflation has previously been associated with alterations in cardiac output and arterial blood pressure (Laws and McIntyre, 1969; Gormezano and Branthwaite, 1972; Singer et al., 1994). Singer et al. (1994) suggested that the increased respiratory rate used by physiotherapists while manually hyperinflating, led to the development of gas trapping which reduced cardiac output. In contrast ventilator hyperinflation allows the physiotherapist to observe the flow patterns generated by each breath, thereby ensuring full exhalation before the next breath is delivered. The risk of cardiovascular compromise due to gas trapping should therefore be reduced.

Research regarding the effects of manual hyperinflation has been difficult to undertake because of the variety of circuits used in clinical practice, confusion regarding the definition of hyperinflation and inconsistency in physiotherapist technique (McCarren and Chow, 1996; Rusterholz and Ellis, 1998; Clarke et al., 1999). Ventilator hyperinflation is an alternative for both physiotherapy treatment and research. The computer software of newer ventilators provides accurate measurement of pressure, volume, flow and fraction of inspired oxygen. The variables of each ventilator hyperinflation breath are quantified leading to improved consistency in clinical practice and accurate data collection for research.

Ventilator hyperinflation was found to be as good as manual hyperinflation in sputum clearance and improving static pulmonary compliance. This suggests that both should be equally effective in treating atelectasis. It also enables both ventilator and manual hyperinflation, as defined in this study, to be used in future research examining patient outcomes in intensive care.

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