Effects of manual hyperinflation and suctioning on respiratory mechanics in mechanically ventilated patients with ventilator-associated pneumonia

Jessica Siu-Ping Choi¹ and Alice Yee-Men Jones²

¹Physiotherapy Department, Queen Elizabeth Hospital ²Department of Rehabilitation Sciences, The Hong Kong Polytechnic University Hong Kong

Ventilator-associated pneumonia results from bacterial colonisation of the aerodigestive tract or aspiration of contaminated secretions into the lower airways. As a consequence of infection of the lung parenchyma and alveolitis, accumulation of inflammatory exudates and infiltration of airway mucosa can lead to unfavourable respiratory mechanics in ventilator-associated pneumonia. Tracheal suction is often employed by nursing staff in the management of mechanically ventilated patients with ventilator-associated pneumonia but this technique has the potential to increase respiratory resistance. Manual hyperinflation is used by physiotherapists to improve lung volume and mobilise secretions and has been shown to increase lung compliance. The effect of manual hyperinflation on airway resistance has not been studied. This study aims to demonstrate an additional mechanical benefit to the respiratory system when manual hyperinflation and suction techniques are combined, by comparing the application of manual hyperinflation and suction with suction alone on static lung compliance (C_L) and inspiratory resistance (R_AW) in mechanically ventilated patients with ventilator-associated pneumonia. Fifteen adult patients with ventilator-associated pneumonia were recruited and acted as their own controls. Manual hyperinflation followed by suction (manual hyperinflation plus suction) and suction alone were applied consecutively, in random order, on two occasions, four hours apart. Respiratory variables, C_L and R_AW, were measured five times and the averaged value documented. Data were recorded before, immediately after, and 30 minutes after each intervention protocol. C_L increased by 22% and R_AW decreased by 21%, up to 30 minutes after manual hyperinflation plus suction, but not after suction alone. This study suggests that manual hyperinflation in conjunction with suction induces beneficial changes in respiratory mechanics in mechanically ventilated patients with ventilator-associated pneumonia. [Choi JSP and Jones AYM (2005): Effects of manual hyperinflation and suctioning on respiratory mechanics in mechanically ventilated patients with ventilator-associated pneumonia. Australian Journal of Physiotherapy 51: 25–30.]

Key words: Physical Therapy, Manual Hyperinflation, Respiratory Mechanics, Mechanical Ventilation, Tracheal Suction

Introduction

Ventilator-associated pneumonia, defined as parenchymal lung infection occurring at least 48 hours after initiation of mechanical ventilation (Morehead and Pinto 2000), is one reason for high costs and prolonged length of stay in the intensive care unit (ICU) (Bowton 1999, Richards et al 1999, Ibrahim et al 2000, Bercault 2001). Ventilator-associated pneumonia is associated with symptoms such as fever, leucocytosis or leucopenia, purulent sputum and the presence of new and persistent pulmonary infiltrates (Valles et al 1995). These symptoms suggest pathology coupled with unfavourable respiratory mechanics such as low lung compliance (C_L) and high airway resistance (R_AW). While subglottic suctioning was reported to reduce the incidence of ventilator-associated pneumonia by as much as 50% (Valles et al 1995), tracheal suctioning remains the common technique adopted by nursing staff in the management of patients with ventilator-associated pneumonia.

‘Chest physiotherapy’ reduces the occurrence of ventilator-associated pneumonia in patients intubated for more than seven days with APACHE scores > 15 (Ntoumenopoulos et al 1998). However ‘chest physiotherapy’ is a collective term for a number of techniques such as gravity-assisted drainage, side-lying positioning, manual hyperinflation and airway suctioning. The individual effect of each component of chest physiotherapy on ventilator-associated pneumonia was not evaluated by Ntoumenopoulos and colleagues (Ntoumenopoulos et al 1998). Manual hyperinflation, commonly adopted by physiotherapists during the management of mechanically ventilated patients, aims to improve lung volume, promote ventilation and mobilise secretions (Jones 1997). It has been shown to improve C_L (Jones et al 1992, Hodgson et al 2000, Patman et al 2000), but the effect of manual hyperinflation on R_AW has not been studied.

An increase in R_AW is caused by accumulation of material within the lumen (secretions), thickening or contraction of the airway wall (infiltration of airway mucosa), and reduced radial traction of the lung interstitium (Nunn 1987, McPhee et al 1997). It is hypothesised that by recruiting alveoli and improving lung volume, manual hyperinflation will improve C_L and reduce R_AW, reversing the unfavourable respiratory mechanics likely to accompany the pathogenesis of ventilator-associated pneumonia. While tracheal suction is an essential technique in the management of patients with ventilator-associated pneumonia, this technique was shown to induce increased respiratory resistance in mechanically ventilated patients (Guglielminotti et al 1998) and is associated with risks and complications such as trauma to the mucosa, alveolar collapse, and hypoxia (Day et al 2002).

This study aims to investigate the effect of tracheal suctioning...
on the respiratory mechanics of patients with ventilator-associated pneumonia and to demonstrate that respiratory mechanics are benefited when manual hyperinflation is used sequentially with suctioning, by comparing the application of manual hyperinflation and suctioning with suctioning alone on $C_L$ and $R_{aw}$ in mechanically ventilated patients with ventilator-associated pneumonia.

Method

Subjects and design Ethics approval was obtained from the Research Committees of the respective university and hospital. A convenience sampling approach was adopted and all patients diagnosed with ventilator-associated pneumonia in the adult ICU within a nine-month period (during which the leaders in each ICU discipline remained unchanged) requiring mechanical ventilation, were recruited to the study. The ICU adopts a diagnosis of ventilator-associated pneumonia when all of the following criteria are satisfied: new and persistent radiological infiltrate, purulent respiratory secretion (± positive Gram stain), temperature over 38.3 degrees Celsius, white cell count $> 10^9$/$l$ or $< 5 \times 10^9$/$l$, deteriorating blood gases, and pneumonia developing after mechanical ventilation for at least 48 hours (Juniper 1999). Subjects with acute respiratory distress syndrome, acute pulmonary oedema, acute head injury, unstable blood pressure, untreated tension pneumothorax, and those with peak inspiratory pressures higher than 40 cmH$_2$O or requiring high respiratory support ($FiO_2 > 0.7$ and PEEP $> 10$ cmH$_2$O) were excluded.

All patients recruited to this study were ventilated by the Puritan Bennett 840$^\circ$ ventilator. Mandatory breaths with a square waveform were delivered with a tidal volume of 8 ml/kg. Measurement of static compliance is accomplished at zero flow, while measurement of airway resistance requires a ml/kg. Measurement of static compliance is accomplished at consistent and constant inspiratory flow (square wave form). $C_L$ and $R_{aw}$ of the respiratory system were measured through activation of the inspiratory pause for at least two seconds during a mandatory breath. Spontaneously breathing patients were temporarily placed on synchronised intermittent mandatory ventilation (SIMV) mode for measurement of $C_L$ and $R_{aw}$. To minimise error induced by a patient’s respiratory effort during data acquisition, the measurements were repeated until at least five consistent readings were obtained. Waveforms were examined to ensure a flat plateau for reliable measurements.

Two ventilators were used throughout the study. The test-retest reliability of the measured variables and the interventilator reliability were established using three test lungs prior to data collection. Five measurements of $C_L$ and $R_{aw}$ with each test lung were taken from each ventilator over two different time periods, four hours apart. The mean values of the five measurements were used for computing the reliability coefficient. This study assumed that the measurement of $C_L$ and $R_{aw}$ by the ventilators was accurate. Absolute precision was not deemed essential as the data were compared using the same patient as their own control. The operational self-check system (designed to ensure optimal function) of the ventilator was performed before use by each patient.

On the day of measurement, each patient received in random order, either manual hyperinflation plus suction or suction alone as the first intervention protocol, and then the other protocol four hours later. Patients were positioned supine and undisturbed for 15 minutes prior to data collection.

Respiratory variables, $C_L$ and $R_{aw}$, were measured five times and the averaged value documented. Data were recorded before, immediately after, and 30 minutes after each intervention protocol. The manual hyperinflation technique was delivered via a Laerdal Silicone Resuscitator$^\circ$ attached to 100% oxygen, flowing at 15 l/min. Four sets of eight bag compressions with both hands were delivered during each manual hyperinflation session. The rate of inflation was 10 breaths per minute. A pressure manometer was inserted in the breathing circuit and each compression was delivered to a peak airway pressure of 40 cmH$_2$O, aiming to maximise lung volume and followed by a second inspiratory pause and then a quick release of the bag to enhance the expiratory flow rate. A positive end expiratory pressure (PEEP) valve was included in the circuit if the patient was treated with PEEP during mechanical ventilation. Tracheal suctioning was applied after delivery of eight manual hyperinflation breaths. The duration of suctioning was limited to 15 seconds. To standardise the suctioning procedure and to enhance aspiration of dry secretions in some patients, one ml of normal saline was instilled via the tracheal tube before manual hyperinflation for all patients.

The suctioning session involved instillation of one ml of normal saline in the tracheal tube, followed by suctioning, applied in an identical manner to that described immediately above, once per minute, for four minutes. The size of the catheters used was FG 12, for both tracheal tube diameters of 7.5 and 8.5 mm. The catheter was inserted fully to the carina and then withdrawn one cm prior to the application of negative pressure. Intermittent negative pressure was applied unless the secretions were very viscous requiring continuous suction for aspiration.

Three experienced physiotherapists were involved in the delivery of the protocols. The same investigator performed all manual hyperinflation techniques, another performed all the suctioning and a third, blinded to the technique and behind a curtain, recorded ventilator-derived data.

Inspired oxygen concentration was maintained at 100% for all patients during the manual hyperinflation and suction procedures. Heart rate, blood pressure and SpO$_2$ were monitored during all procedures.

Statistical analysis Two-way repeated measures ANOVA, with treatment and time as the within-subject factors, was used to determine if the changes in $C_L$ and $R_{aw}$ of the respiratory system induced by the two interventions were different. Any changes in $C_L$ and $R_{aw}$ at the three data collection points were also examined by post-hoc tests with Bonferroni adjustments (Portney et al 1993). The level of significance was set at $p < 0.05$. All data were analysed using SPSS for Windows version 10.0.

Results

The intraclass correlation coefficients (ICC) for test-retest reliability of $C_L$ and $R_{aw}$ with both ventilators were 1.00 (95% confidence intervals 0.97 to 1.00). For measurements between the two ventilators, the ICC for $C_L$ was 0.99 (95% CI 0.91 to 1.00) and the ICC for $R_{aw}$ was 1.00 (95% CI 0.99 to 1.00).

Fifteen patients (eight males) with mean age of 59.9 (SD 16.8, range 25 to 83) years were recruited to the study. Descriptive data for these patients are given in Table 1. The mean $C_L$ of the respiratory system increased by 22%
immediately after manual hyperinflation plus suction from 35.2 (SD 4.9) to 43.1 (SD 6.4) ml/cmH₂O and this was maintained at 30 minutes post-intervention. Changes in CL after suctioning alone were not significant (Table 2). There was no difference in CL between the group pre-intervention levels (p = 0.32), but the CL immediately after and 30 minutes post manual hyperinflation plus suction was significantly higher than suction (p < 0.001 at both times).

There was no difference in baseline Raw before the manual hyperinflation plus suction or suction intervention (p = 0.38). The Rₜₚ of the respiratory system decreased from pre to post manual hyperinflation plus suction level, with a further decrease by as much as 21% at 30 minutes post intervention. The difference was statistically significant between the pre and at 30 minute post manual hyperinflation (p = 0.004). The difference in Rₜₚ immediately after suction was not significant (p = 0.61).

There was no interaction between the effect and the order of intervention (p > 0.05).

Heart rate, blood pressure, and SpO₂ were all stable and no adverse haemodynamic events were noted during the whole physiotherapy and recording period.

**Discussion**

This study showed that the suction alone procedure, as described, had no adverse effect in our patients with ventilator-associated pneumonia, and that manual hyperinflation plus suction improved the measured respiratory mechanics in this patient cohort. Static lung compliance (CL) improved immediately post manual hyperinflation and the improvement was maintained 30 minutes post intervention. The 22% improvement in CL was comparable to the 16% (Jones et al 1992), 15% (Patman et al 2000), and 30% (Hodgson et al 2000) improvements reported by other workers in mechanically ventilated patients. The difference in improvement may be a ‘dose’ effect (a combination of volume delivered, number of breaths, as well as total treatment time) or it may be related to the circuit type employed by the physiotherapist. Hodgson and colleagues (Hodgson et al 2000) used six sets of six manual breaths with a McGill circuit whereas the current study used four sets of eight manual breaths delivered by a Laerdal circuit.

Lung compliance increased when inspiratory time was prolonged during mechanical ventilation, and a sustained deep inflation ‘likely to occur during bagging’ might cause re-
Changes in static compliance (CL) and inspiratory resistance (RAW) in the respiratory system of the 15 patients after the intervention was 2.3 cmH2O/l/sec. This value is not statistically significant but would also have a significant clinical impact, as the RAW ranges from 1.5 to 2 cmH2O/l/sec in normal adults (Pride 2000).

In contrast to the findings by Guglielminotti and colleagues (Guglielminotti et al 1998), our study showed no significant changes in RAW immediately after tracheal suctioning, with or without manual hyperinflation. The authors in that study suggested that the significant increase in airway resistance at 30 seconds post suctioning was likely a consequence of a transient bronchoconstrictor response induced by mechanical tracheal stimulation, and the airway resistance returned to baseline levels one minute following suctioning. The absence of this transient increase in airway resistance in our study could probably be due to differences in the type of catheter used and the actual technique employed. Continuous suction with a 4.7 mm diameter catheter was used in Guglielminotti’s study, but in the current study intermittent suction was employed using a 4 mm diameter catheter. Furthermore, in Guglielminotti’s study, tracheal pressure was measured with a 2.7 mm diameter, multi-perforated catheter (which was connected to a transducer), positioned 1 cm above the distal tip of the tracheal tube. Passage of a 4.7 mm diameter suction catheter through a tracheal tube, the diameter of which was already compromised by the presence of a 2.7 mm diameter measurement catheter, could explain the observed transient decrease in RAW in Guglielminotti’s study.

None of our patients produced large amount of secretions and, because only minimal amounts of secretions were removed during both manual hyperinflation and suction interventions, it was not likely that the reduction of RAW was due to sputum removal. We thus hypothesise that manual hyperinflation improved CL because lung volume increased and therefore airway diameter increase as a result of the improved radial traction within the lung. Airway resistance is a function of the fourth power of the airway radius (Nunn 1987 p. 47), and therefore a small increase in airway radius (Nunn 1987 p. 47), and therefore a small increase in airway diameter as a result of the improved radial traction will significantly decrease airway resistance.

Ventilator-associated pneumonia arises from bacterial colonisation of the aerodigestive tract and aspiration of contaminated secretions into the lower airways (Craven et al...
1995, Craven et al 1996). Secretion retention and decreased lung volume are the major clinical problems. Suction alone is a frequent technique adopted by the nursing staff in the management of ventilator-associated pneumonia to minimise the risk of bacterial colonisation in the airway. Our data suggest that tracheal suction alone was not accompanied by adverse effects and manual hyperinflation plus suction reduced $R_{aw}$ and improved $C_{T}$ by more than 20%. These improved respiratory mechanics suggest manual hyperinflation plus suction may be an effective intervention to improve the lung function of patients with ventilator-associated pneumonia. The effect of manual hyperinflation plus suction on prevention and treatment of ventilator-associated pneumonia requires further investigation.

**Limitation of the study** Pulmonary mechanics would ideally be measured using an oesophageal balloon and intrathoracic pressure (Gibson 1999). This is, however, an invasive, complex, and costly procedure. Although the number of patients in this study was only 15, our data showed that the power of this study was 0.8 with the effect size for $C_{T}$ and $R_{aw}$ greater than 0.7 and 0.5, respectively. Theoretically $C_{T}$ should be measured with patients sedated and ventilated with controlled mandatory breaths. Most of our patients had the ability to generate some respiratory effort while receiving SIMV. It was unethical to fully sedate the patients to facilitate controlled mandatory ventilation for this study. Efforts were therefore made to ensure measurements were taken during mandatory breaths, and the waveform of each delivered breath was monitored closely to ensure measurements formed reliable data. Our recorded data are comparable between treatments in the same patient, with the same equipment and the same operator, thereby reducing error and increasing the validity of comparison.

In conclusion, this is the first study to report the effect of manual hyperinflation on $R_{aw}$. Our results show that suction alone did not cause deterioration in $C_{T}$ and $R_{aw}$ and thus can probably be used safely in this patient group. This study demonstrated that the use of manual hyperinflation in addition to suction improved respiratory mechanics compared to suction alone.

**Acknowledgement** The authors are indebted to Mr Stephen Chan, Mr Ka-wai Chau, and Miss Rufina Lau for their kind assistance with data collection during the study. We are also grateful to Mr Peggo KW Lam for his assistance in the statistical analysis.

**Footnotes**
- Puritan Bennett, Pleasanton, CA, USA
- Test Lung 190, ServoCare; PB7200 Test Lung, model no. 4-000612-00 and model no. 4-011355-00
- Laerdal Medical Corp., NY, USA

**Correspondence** Dr Alice Jones, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong. Email: <rsajones@polyu.edu.hk>

**References**


Jones AYM, Hutchinson RC and Oh TE (1992): The effects of bagging and percussion on total static compliance of the respiratory system. *Physiotherapy* 78: 661–666.


