Comparison of the effectiveness of manual and ventilator hyperinflation at different levels of positive end-expiratory pressure in artificially ventilated and intubated intensive care patients

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BACKGROUND: Manual hyperinflation (MHI) and ventilator hyperinflation (VHI) are two methods of recruitment maneuvers used in ventilated patients to improve lung compliance and secretion mobilization. The use of VHI may minimize the adverse effects of disconnection from the ventilator, but it is uncertain whether high levels of positive end-expiratory pressure (PEEP) would decrease the peak expiratory flow rate (PEFR) and consequently affect secretion clearance.

OBJECTIVES: The aim of this study was to compare the effectiveness of MHI and VHI in terms of clearing pulmonary secretions (sputum wet weight and PEFR), improving static respiratory system compliance and oxygenation (arterial oxygen tension/fraction of inspired oxygen), and altering mean arterial pressure, heart rate, and carbon dioxide output at different levels of PEEP.

METHODS: This was a randomized crossover study involving 14 general intensive care patients who were intubated and mechanically ventilated.

RESULTS: Sputum production was similar in both techniques and levels of PEEP. There were no differences in improvement in oxygenation and static respiratory system compliance between MHI and VHI. However, VHI increased Cst significantly at 30 minutes posttreatment ($P = .012$), and a significant difference was observed between levels 5 and 7.5 cmH2O ($P = .02$) of PEEP for MHI. MHI generated higher PEFR than VHI ($P < .05$). No adverse change in heart rate or mean arterial pressure was observed during either technique; however, VCO2 was significantly different for techniques ($P = .045$) and over time ($P = .05$).

CONCLUSION: The VHI technique seems to promote greater improvements in respiratory mechanics with less metabolic disturbance compared with MHI. Other variables such as sputum production, hemodynamics, and oxygenation were affected similarly by both techniques. (Heart Lung® 2006;35:334–341.)

IMPLICATION STATEMENT

It is uncertain whether the use of the ventilator to deliver hyperinflation breaths would produce similar improvements in lung compliance, oxygenation, and secretion clearance as those obtained with the MHI circuit but without the adverse effects of disconnection from the ventilator. This study is relevant to intensive care practice because it examines techniques commonly used by respiratory therapists, physiotherapists, and nurses in several countries.
tensive care patients, with manual hyperinflation (MHI) and airway suctioning being techniques frequently applied. MHI is performed by delivering a large tidal volume combined with an inspiratory plateau and a fast release of the resuscitation bag. The short-term effectiveness of MHI in improving oxygenation and pulmonary compliance, reexpanding areas of atelectasis, and clearing pulmonary secretions has been widely demonstrated. However, there is controversy in whether patients ventilated on high levels of positive end-expiratory pressure (PEEP) should be disconnected from the ventilator to receive MHI, because disconnection would cause loss of functional residual capacity (FRC), decrease in oxygenation, and shear stress of distal lung units. To prevent adverse effects of disconnection, the ventilator may be used to deliver increased tidal volume, a technique called ventilator hyperinflation (VHI). Berney and Denehy, in a crossover study, compared the effectiveness of VHI and MHI in 20 intensive care patients and concluded that there was no significant difference between the two techniques in terms of amount of secretions cleared and improvement in lung compliance. However, the influence of the level of PEEP was not investigated. High levels of PEEP may cause a decrease in the mouth to alveolus pressure gradient and consequently reduce the expiratory flow rate to a level at which secretion clearance is ineffective.

Therefore, the main aim of this study was to compare the effectiveness of MHI and VHI on respiratory mechanics (static compliance [Cst]), oxygenation (arterial oxygen tension [PaO2]/fraction of inspired oxygen [FiO2] ratio), and secretion removal (weight of sputum and peak expiratory flow rate [PEFR]) at different levels of PEEP. Because previous studies have found significant alteration in hemodynamic and metabolic responses during MHI and other physiotherapy techniques in critically ill patients, a secondary aim was to investigate hemodynamics (heart rate [HR] and mean arterial pressure [MAP]) and metabolic response (carbon dioxide output [VCO2]) during MHI and VHI.

**MATERIALS AND METHODS**

This was a single-blind, randomized, crossover study involving 14 mechanically ventilated patients in the Alfred Hospital Intensive Care Unit. Ethical approval was obtained from both Alfred Hospital and La Trobe University Human Ethics Committees. Informed consent from next of kin was obtained. Patients were included in the study if they were more than 18 years of age, mechanically ventilated on synchronized intermittent mandatory ventilation (SIMV) or continuous airway pressure/pressure support ventilation, on PEEP lower than or equal to 10 cmH2O, with an arterial line in situ, and had required mechanical ventilation for a number of precipitating factors, including head injury, surgery, sepsis, and primary respiratory conditions.

The exclusion criteria involved hemodynamic instability as evidenced by MAP less than 70 mm Hg, pulmonary artery occlusion pressure or central venous pressure less than 6 mm Hg, and/or high doses of vasoactive drugs, patients ventilated on pressure-controlled ventilation or airway pressure release ventilation, undrained pneumothorax, pulmonary edema, and severe head injury with refractory intracranial pressure. Patients were also excluded if they fulfilled the criteria for acute respiratory distress syndrome, peak inspiratory pressure (PIP) greater than 35 cmH2O on the ventilator, using nitric oxide in the ventilator circuit, ventilating on PEEP greater than 10 cmH2O, and FiO2 greater than 0.8. These patients were excluded from the study because of their potential to deteriorate if disconnected from the ventilator for MHI to be performed.

**Procedure**

The order of the techniques was randomly selected using computer-generated random permutation. MHI and VHI were performed at least 3 hours apart to minimize any carryover effect. Patients were maintained in the same position for both techniques, with the affected lung uppermost with unilateral lung disease and in the supine position with bilateral lung compromise.

Patients were appropriately positioned 20 minutes before baseline measures. A flow sensor (Series 3 Pediatric/Adult Flow Sensor, Novametrix Medical Systems Inc., Wallingford, CT) with a carbon dioxide sensor (CAPNOSTAT CO2 Sensor, Novametrix Medical Systems Inc.) was inserted into the ventilator circuit and attached to the CO2SMO respiratory mechanics monitor (CO2SMO Plus Model 8000, Novametrix Medical Systems Inc.) before initial measurement. This monitor recorded tidal volume (Vt), PEFR, PIP, and CO2 production. This monitor also gave a visual representation of the waveforms, allowing the accurate delivery of Vt and a limit on PIP to be enforced. One researcher performed the interventions during the entire study, and a second researcher collected all outcome mea-
sures. The second researcher was blind to the allocated method of treatment.

**Manual hyperinflation.** The MHI technique was performed using the self-inflating Laerdal resuscitation bag (Laerdal Medical Ltd., Kent, UK) with 15 L/min of fresh gas flow. A PEEP valve, consisting of disposable threshold resistors (Vital Signs Inc, Totowa, NJ), was connected to the Laerdal circuit and adjusted to deliver the level of PEEP currently dialed on the mechanical ventilator. With a two-handed technique, hyperinflation breaths with FIO\(_2\) of 1.0 were delivered, with a 2-second inspiration, 2-second inspiratory pause, and 1-second expiration, with a rate of 8 breaths/min. The same person performed the techniques during the entire study, limiting the variability that can occur with different hand sizes, hand strength, or gender.

MHI was delivered for 3 minutes, followed by airway suctioning.

**Ventilator hyperinflation.** The ventilator (Bennett 7200, Nellcor-Puritan-Bennett, Pleasanton CA) was adjusted to deliver hyperinflation breaths aiming at tidal volume of 130% of the set tidal volume and PIP was limited to 40 cmH\(_2\)O. The rate was 7 to 8 breaths per minute, and FIO\(_2\) was increased to 1.0 for the duration of the technique (3 minutes), which was followed by airway suctioning. The baseline PEEP was maintained during VHI.

### Measurements

PEFR and CO\(_2\) production were measured using a flow and CO\(_2\) sensor connected to the patient’s airways and to the CO\(_2\)SMO respiratory mechanics monitor (CO\(_2\)SMO Plus Model 8000, Novametrix Medical Systems Inc, Wallingford, CN). All information from the CO\(_2\)SMO monitor was simultaneously recorded in the Analysis Plus computer program.

Static lung compliance was recorded by the static measures function device on the Bennett 7200 ventilator where a plateau pressure was obtained by including an inspiratory pause of 2 seconds into the mandatory breath. Spontaneously breathing patients were changed temporarily to SIMV with 8 breaths/min and tidal volume of 8 mL/kg for measurement of Cst. Three measurements were taken before, immediately after, and 30 minutes after MHI or VHI.

\(\text{PaO}_2/\text{FiO}_2\) ratio was calculated from arterial blood samples taken immediately before and immediately after MHI and VHI. Four milliliters of arterial blood were drawn into a syringe containing heparin and analyzed by a blood gas machine (Bayer Australian Limited 865, Pymble, NSW, CAN 000128714). This procedure was standardized across subjects.

HR and MAP were read directly from the monitoring system (Merlin pressure module M1006A Hewlett Packard, Palo Alto, CA) and recorded every minute before, during, and for 5 minutes after MHI and VHI.

At the conclusion of both MHI and VHI, one suction procedure was performed through the closed suction system (Ballard Trach Care, model 22103-4, Ballarat medical products, Draper, UT). Sputum wet weight was collected in a preweighed sputum trap (Unomedical, model 455.40.001, Unomedical Australia) connected to the suction catheter, and on completion of suction procedure, the catheter was flushed with standard 4 mL saline to clear any secretions.

The main effects of technique, time, or technique X time for each variable were investigated using mixed between-within analysis of variance, with planned comparisons. The influence of the level of PEEP and order effect on the dependent variables Cst, sputum, PEFR, and \(\text{PaO}_2/\text{FiO}_2\) were also analyzed as covariates. The independent factor in the analysis was the technique (MHI and VHI); the covariates were the level of PEEP (5, 7.5, and 10 cmH\(_2\)O) and order effect, and the dependent variables were those mentioned above. The analysis included all the main effects and second-level interactions. If the main effects proved significant, planned comparisons post hoc were performed using Bonferroni multiple comparisons adjustment.

Sample size calculation was based on lung compliance using the mean difference and standard deviation from a previous study.\(^9\) For the given effect size of 1.1, alpha = .05 (two-tailed), and power of 80%, the sample size estimated was 13 subjects.\(^{17}\) Data are presented as mean values and standard deviation unless otherwise stated.

### RESULTS

A total of 14 subjects were included in the study (9 males, 5 females), ranging in age from 23 to 85 (mean 62.23 years), with a mean Apache II score of 17.5 (6–30) and trauma as the most common diagnosis. Table I presents a description of the subjects involved in the study. Ventilatory settings can be found in Table II.

There was no significant difference in the change in static compliance between techniques (\(F = .01, df 1, P = .91\)). Both techniques demonstrated an improvement in static respiratory system compliance over time; however, the improvement was only sig-
### Table I
Characteristics of subjects included in the study

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>CXR</th>
<th>APACHE II</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>23</td>
<td>M</td>
<td>Trauma</td>
<td>NAD</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>59</td>
<td>M</td>
<td>Guillain-Barré + respiratory failure</td>
<td>L/R base cons</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>74</td>
<td>M</td>
<td>Abdominal tumor</td>
<td>L base cons</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>32</td>
<td>M</td>
<td>Necrotizing fascitis/myositis right forearm</td>
<td>L/R base cons</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td>74</td>
<td>F</td>
<td>Trauma</td>
<td>L base cons</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>47</td>
<td>M</td>
<td>Trauma</td>
<td>L base cons</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>85</td>
<td>M</td>
<td>Rupture AAA</td>
<td>R base cons</td>
<td>23</td>
</tr>
<tr>
<td>8</td>
<td>70</td>
<td>M</td>
<td>Trauma</td>
<td>R base cons</td>
<td>16</td>
</tr>
<tr>
<td>9</td>
<td>55</td>
<td>M</td>
<td>Liver carcinoide tumor</td>
<td>R base coll/L base opac</td>
<td>19</td>
</tr>
<tr>
<td>10</td>
<td>84</td>
<td>F</td>
<td>Trauma</td>
<td>L base pleural effusion</td>
<td>14</td>
</tr>
<tr>
<td>11</td>
<td>58</td>
<td>F</td>
<td>Type A aortic dissection and renal artery stenosis</td>
<td>L base cons</td>
<td>16</td>
</tr>
<tr>
<td>12</td>
<td>55</td>
<td>M</td>
<td>Trauma</td>
<td>L/R base coll + pleural effusion</td>
<td>19</td>
</tr>
<tr>
<td>13</td>
<td>74</td>
<td>F</td>
<td>Subarachnoid haemorrhage, two aneurysms</td>
<td>Discrete L/R base pleural effusion</td>
<td>—</td>
</tr>
<tr>
<td>14</td>
<td>82</td>
<td>F</td>
<td>Colostomy, AAA rupture</td>
<td>L/R base pleural effusion + coll + cons (+L)</td>
<td>30</td>
</tr>
</tbody>
</table>

*CXR*. Chest xray; *NAD*, no abnormality detected; *L*, left; *R*, right; *coll*, collapse; *cons*, consolidation; *L+*, more left side; *AAA*, abdominal aortic aneurysm.

### Table II
Ventilatory settings of subjects involved in the study

<table>
<thead>
<tr>
<th>Subject</th>
<th>Mode</th>
<th>Vt (L) M/S</th>
<th>RR (bpm) M/S</th>
<th>PS</th>
<th>PEEP</th>
<th>Fio2</th>
<th>PIP</th>
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<tr>
<td>1</td>
<td>CPAP</td>
<td>.56/.56</td>
<td>0/16</td>
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<td>.3</td>
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<td>CPAP</td>
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<td>0/7</td>
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<tr>
<td>3</td>
<td>SIMV</td>
<td>.65/.71</td>
<td>8/5</td>
<td>8</td>
<td>5</td>
<td>.3</td>
<td>22</td>
</tr>
<tr>
<td>4</td>
<td>CPAP</td>
<td>.58/.58</td>
<td>0/18</td>
<td>10</td>
<td>5</td>
<td>.5</td>
<td>n/a</td>
</tr>
<tr>
<td>5</td>
<td>SIMV</td>
<td>.55/0</td>
<td>10/0</td>
<td>8</td>
<td>7.5</td>
<td>.3</td>
<td>23</td>
</tr>
<tr>
<td>6</td>
<td>SIMV</td>
<td>.70/0</td>
<td>10/0</td>
<td>8</td>
<td>10</td>
<td>.4</td>
<td>27.7</td>
</tr>
<tr>
<td>7</td>
<td>CPAP</td>
<td>.8/.8</td>
<td>0/10</td>
<td>15</td>
<td>10</td>
<td>.4</td>
<td>n/a</td>
</tr>
<tr>
<td>8</td>
<td>SPONT</td>
<td>.54/.54</td>
<td>0/26</td>
<td>8</td>
<td>7.5</td>
<td>.45</td>
<td>n/a</td>
</tr>
<tr>
<td>9</td>
<td>CPAP</td>
<td>.1/.1</td>
<td>0/12</td>
<td>5</td>
<td>7.5</td>
<td>.35</td>
<td>n/a</td>
</tr>
<tr>
<td>10</td>
<td>SIMV</td>
<td>.55/.58</td>
<td>11/11</td>
<td>15</td>
<td>5</td>
<td>.4</td>
<td>28.3</td>
</tr>
<tr>
<td>11</td>
<td>CPAP</td>
<td>.34/.34</td>
<td>0/30</td>
<td>12</td>
<td>5</td>
<td>.35</td>
<td>n/a</td>
</tr>
<tr>
<td>12</td>
<td>CPAP</td>
<td>.45/.45</td>
<td>0/33</td>
<td>12</td>
<td>7.5</td>
<td>.4</td>
<td>n/a</td>
</tr>
<tr>
<td>13</td>
<td>CPAP</td>
<td>.49/.49</td>
<td>0/20</td>
<td>12</td>
<td>7.5</td>
<td>.3</td>
<td>n/a</td>
</tr>
<tr>
<td>14</td>
<td>CPAP</td>
<td>.41/.41</td>
<td>0/22</td>
<td>12</td>
<td>5</td>
<td>.4</td>
<td>n/a</td>
</tr>
</tbody>
</table>

*CPAP*. Continuous positive airway pressure; *SIMV*, synchronized intermittent mandatory ventilation; *SPONT*, spontaneous ventilation; *Vt (L) M/S*, tidal volume in liters mandatory/spontaneous; *RR*, respiratory rate; *PS*, pressure support; *PEEP*, positive end-expiratory pressure; *Fio2*, fraction of inspired oxygen; *PIP*, peak inspiratory pressure.
significant for the VHI technique. VHI produced an increase in Cst at 30 minutes posttreatment (mean difference [md] = 5.50, standard error [SE] = 1.48, \( P = .012 \)). Compared with baseline, a mean improvement of approximately 6 mL/cmH2O (12%) occurred after VHI. When the covariate PEEP level was analyzed during the MHI technique, there was a statistically significant difference for Cst between levels 5 and 7.5 cmH2O of PEEP (md = 20.06, SE = 5.64, \( P = .02 \)) with PEEP of 7.5 and 10 cmH2O presenting higher values than 5 cmH2O before, during, and after intervention. However, no statistically significant difference was observed among the levels of PEEP for VHI (F = 1.25, df = 2, \( P = .33 \)) (Fig 1).

There was no significant difference in sputum production between the techniques (F = .92, df = 1, \( P = .34 \)) or among the levels of PEEP (F = .73, df = 2, \( P = .39 \)), with MHI producing 1.31 g (± 81) and VHI 1.87 g (± 2). On further examination of sputum data, it was found that data were skewed in the VHI treatment by patient 8, who produced a large amount of sputum (7.64 g). Data were reanalyzed discarding the data of patient 8 and VHI mean wet weight of sputum decreased to 1.43 (± 1.17), and there was not a significant difference between the two techniques (\( P = .76 \)). To investigate whether there was any relationship between the amount of sputum removed and the level of consciousness (sedation score), Pearson product-moment correlation coefficient was used. During MHI, there was a strong negative correlation between the two variables (\( r = -.58, n = 14, P < .05 \)), with high levels of sedation associated with lower amounts of sputum removed. However, during VHI, there was a small and not significant association between the two variables (\( r = .16, n = 14, P = .57 \)).

For PEFR, there was a statistically significant difference between MHI and VHI (md = 6.5, SE = 2.92, \( P = .036 \)), with MHI (34.31 ± 6.6) demonstrating higher PEFR than VHI (27.8 ± 8.16). In addition, there was no significant difference in PEFR in either technique at different levels of PEEP (F = .53, df = 2, \( P = .65 \)).

There was no significant difference in improvement on PaO2/FiO2 between techniques (F = .50, df = 1, \( P = .48 \)), over time (F = 1.75, df = 1, \( P = .2 \)), or among levels of PEEP (F = 0.76, df = 2, \( P = .39 \)).

There were no significant changes in HR or MAP during either technique. However, there was a significant difference in VCO2 between techniques (md = 23.39, SE = 10.95, \( P = .045 \)) and over time (F = 3.31, df = 2, \( P = .05 \)). As shown in Fig 2, an upward trend in VCO2 was observed during MHI, whereas for VHI, there was a downward trend in VCO2 during all periods. When further analysis was performed using Bonferroni adjustment for multiple comparisons, during MHI, there was a significant difference between pre- and during intervention (md = 48.13, SE = 7.97, \( P = .001 \)) and between pre- and post-intervention (md = 65.85, SE = 9.05, \( P < .01 \)), whereas for VHI, no statistically significant alteration in VCO2 was observed at the same time intervals.

There was also a significant difference in tidal volume between the two techniques, with VHI generating larger tidal volumes (md = 105.55, SE = 31.46, \( P = .003 \)). The influence of the order, which

**Fig 1** Changes in Cst over time and for different levels of PEEP during MHI (a) and VHI (b). MHI, Manual hyperinflation; VHI, Ventilator hyperinflation; Cst, Static compliance; PEEP, Positive end-expiratory pressure.
the techniques were applied, on the dependent variables was also investigated, and no significant difference was observed.

**DISCUSSION**

This study compared the effect of MHI and VHI on respiratory mechanics, secretion yield, oxygenation, hemodynamic, and metabolic responses in ventilated patients on different levels of PEEP. The main findings were that VHI produced an increase in Cst and a decrease in VCO₂. There was no difference between the two techniques in wet weight of secretion, oxygenation, or hemodynamics.

In previous studies, MHI has been associated with improvement in respiratory system compliance; however, in the current study, the improvement in static respiratory system compliance over the three periods of time (pre-, during, and post-intervention) was only observed after the application of ventilator hyperinflation technique.

Cst is considered an important clinical outcome measure, and it may be used to predict mortality in patients with respiratory failure. The most accurate method of measuring Cst is by using an esophageal balloon and measuring the intrathoracic pressure. However, this is a very invasive and costly procedure. There is some limitation in the measurement of Cst in the current study, because strictly, subjects should be fully paralyzed. However, because techniques were compared within patients on the same sedation scale, valid comparisons can be made with reduced error. Evidence exists to suggest that improvement in lung compliance after hyperinflation breaths occurs because of the reexpansion of previously collapsed lung units. When lung inflation is sustained for a few seconds, as during the two techniques in this study, permits a more uniform distribution of gas, recruiting interdependent collapsed alveoli through collateral ventilation or intercommunicating channels and consequently improving functional residual capacity (FRC). The improvement in static respiratory system compliance that was only observed in the VHI group could be explained by the fact that this technique does not involve disconnection from the ventilator, avoiding de-recruitment of alveolar units. In addition, the MHI circuit used in the majority of the studies that demonstrated improvement in respiratory system compliance after MHI used a resuscitation circuit (Mapleson-C circuit [Warne Surgical Products Ltd, UK]) with different characteristics from the one used in the current study. Because of protocol requirements within this intensive care unit, a Laerdal manual resuscitation bag was used. It is possible that if the Mapleson-C or a resuscitation bag with similar characteristics had been used for this study, an improvement in static lung compliance for the MHI group may have been observed.

When the influence of the level of PEEP on Cst was analysed, it was observed that Cst was higher when the patient was being ventilated on PEEP level of 10 cmH₂O. This may be explained by the fact that higher levels of PEEP may maintain alveolar stability, increase FRC, and reduce areas of intermittent airway collapse or atelectasis, consequently causing an improvement in lung compliance. In addition, patients on a PEEP level of 10 cmH₂O showed a tendency toward greater improvement in Cst at 30 minutes post-intervention, demonstrating a sustained effect. This clearly reflects the importance of maintaining the “optimal” level of PEEP after recruitment maneuver techniques to maintain alveolar stability and keep the reexpanded alveoli open at the end of expiration.

Another main finding in the current study was the difference in PEFR observed between the two techniques. The PEFR generated after the application of MHI was significantly higher than when VHI was implemented. Tidal volume has been positively associated with PEFR because when larger tidal volumes are generated, the elastic recoil of the lungs and chest wall cause an increase in expiratory flow, which would consequently assist in secretion mobilization. However, in the current study, larger tidal volumes were generated during the application of VHI, whereas higher PEFR was observed during MHI. A justification could be that the slow inspiratory phase followed by a fast, abrupt, and complete release of the resuscitation bag by the physiotherapist has a more significant influence in generating higher PEFR than has the isolated elastic recoil of the lungs after large breaths.
However, to promote pulmonary secretion movement, it is not necessary to generate PEFR as high as during cough.\textsuperscript{26} With slower expiratory flow rates it is possible to mobilize pulmonary secretion, provided the conditions for formation of annular two-phase gas liquid flow are met.\textsuperscript{27,28} The concept of annular two-phase gas liquid flow has been investigated by Kim and coworkers, and they stated that in order to occur upward movement of secretions in the airways, it is necessary to have an inspiratory flow rate of at least 10% slower than the expiratory flow rate, that is, an inspiratory to expiratory flow rate ratio of less than 1. When MHI was performed in the current study, this pattern was obtained in all inspiratory breaths (peak inspiratory flow (PIFR): PEFR = 1.01 ± 0.21), whereas for VHI, the inspiratory flow rate for some breaths was higher than the expiratory flow rate (PIFR:PEFR = 1.27 ± 0.24). This may be explained by the high PIFR generated during VHI. Because inspiratory flow is volume divided by time of inspiration, the very large tidal volumes observed during this technique and the short inspiratory time, which could not be previously manipulated by the physiotherapists, might have caused the inspiratory flow to increase to a level at which the condition for annular two-phase gas liquid flow was not met. In the current study, there was no significant difference in the weight of wet sputum removed during both techniques; however, the population investigated was not characteristic of having large amounts of pulmonary secretions. In a different population, VHI may not be capable of efficiently clearing pulmonary secretion. Further research is needed to confirm these findings.

This is the first study that we are aware of to analyze the influence of PEEP on PEFR, and there was no significant difference in PEFR in MHI at different levels of PEEP. During VHI, there was a trend toward a lower PEFR when performed in patients ventilated on PEEP of 10 cmH\textsubscript{2}O, which suggests that this technique is more influenced by the level of PEEP when compared with MHI. It is possible that higher levels of PEEP may render VHI ineffective as a secretion clearance technique. A larger sample size could perhaps demonstrate a statistically significant difference. These results conflict with a previous in vitro study by our team,\textsuperscript{13} in which higher levels of PEEP decreased PEFR during MHI.

A strong negative correlation was observed between the sedation score and the amount of sputum removed during MHI. This finding suggests that patients may have an active participation in mobilizing secretion during suction when they have a more superficial sedation. This may be explained perhaps by a more active cough reflex and contraction of diaphragm and abdominal muscles, which would increase the expiratory flow and assist secretion mobilization.\textsuperscript{29}

Chest physiotherapy (consisting of positioning, percussion, vibration, and airway suctioning) has been shown to cause metabolic stress in critically ill patients, with significant increase in both oxygen consumption (VO\textsubscript{2}) and carbon dioxide production (VCO\textsubscript{2}).\textsuperscript{15,30–32} However, there is no study in the literature analyzing the metabolic alteration observed when MHI or VHI was added to the treatment. There was a significant increase in VCO\textsubscript{2} during MHI, which may be explained mainly by disconnection from the ventilator, causing agitation and discomfort.

There were no significant changes in hemodynamics during either VHI or MHI. This finding is in contrast with some studies previously published.\textsuperscript{14,33–35} A possible explanation is that in the current study there were strict inclusion/exclusion criteria ensuring adequate fluid loading and cardiovascular stability before intervention.

For both techniques, there was a trend toward an improvement in PaO\textsubscript{2}/FiO\textsubscript{2}; however, this was not clinically or statistically significant. This is in contrast with other studies investigating MHI.\textsuperscript{8} The techniques may have reduced the amount of atelectasis, especially during VHI, as demonstrated by the improvement in static respiratory system compliance. However, to minimize impairment in gas exchange in areas of atelectasis there is redistribution of blood flow through hypoxic pulmonary vasoconstriction from lung collapse regions to areas of low partial pressure.\textsuperscript{36} After the application of the therapeutic techniques and re-expansion of collapsed lung units, increased areas of dead space, where areas of the lung were well ventilated but poorly perfused, may have led to a non-significant improvement in oxygenation. That improvement may have occurred a few minutes after the treatment. In addition, in the studies that demonstrated such improvement in oxygenation,\textsuperscript{8,19} a Mapleson-C resuscitation bag was used, which could have influenced the results for the reasons discussed previously.

**LIMITATIONS OF THE STUDY**

A limitation of the current study was that because of ethical concerns, an arterial blood gas measurement could not be retrieved after 30 minutes of treatment. This would have enabled a more clear evaluation of the effect of these two treatments on oxygenation parameters. Also, the use of
an esophageal balloon would make the measurement of Cst more precise. In addition, the effect of the Mapleson-C circuit instead of the Laerdal circuit on the variables studied in this study could be investigated in future studies.

CONCLUSION

VHI seems to be a safe and effective method of treatment. VHI has more beneficial effects than MHI on improving respiratory mechanics, and less effect on metabolism. Both MHI and VHI were capable of removing similar amounts of pulmonary secretions in the population investigated in the current study, despite the fact that MHI generated higher PEFR and lower PIFR:PEFR. This suggests that VHI may be used to substitute for MHI when the aim of the technique is to improve respiratory mechanics and enhance secretion clearance in general intensive care patients mechanically ventilated on PEEP of 10 cmH₂O or less who do not produce large quantities of sputum.

REFERENCES


Manual and ventilator hyperinflation

36. Savian et al. Manual and ventilator hyperinflation