Manual hyperinflation: consistency and modification of the technique by physiotherapists

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ABSTRACT Background and Purpose: The present study aimed to evaluate the consistency with which physiotherapists apply manual hyperinflation to a test lung using the Air-Viva-2 or Mapleson-B resuscitation circuit, and their ability to modify the technique as pulmonary characteristics change. Method: A quasi-experimental, randomized, repeated-measures design was used to study 16 volunteer physiotherapists performing manual hyperinflation to a test lung simulating three clinical situations. Each subject applied manual hyperinflation to the test lung for each simulation three times in one day using the resuscitation circuit that they would normally use in their clinical practice. Eight subjects used the Air-Viva-2 circuit and eight used the Mapleson-B circuit. Measurements of tidal volume (VT), peak airway pressure (Paw) and fraction of delivered oxygen (FDO2) were recorded during each testing period. Inflation rate and minute volume were calculated. Results: As compliance decreased and airway resistance increased, VT decreased and Paw increased. Of the eight subjects using the Air-Viva-2 circuit, only three subjects delivered greater than 0.80 FDO2. All subjects using the Mapleson-B circuit delivered greater than 0.85 FDO2. Conclusions: Subjects demonstrated good consistency in the application of manual hyperinflation for all three simulations and modified their technique appropriately as simulated pulmonary characteristics changed.

Key words: manual hyperinflation, physiotherapy, reliability, resuscitation equipment

INTRODUCTION
Manual hyperinflation of the lungs is frequently employed by physiotherapists as part of the respiratory care of artificially ventilated patients and involves the manual delivery of a volume of gas to the lungs via resuscitation circuits such as the Air-Viva-2 or Mapleson-B. The purpose of manual hyperinflation, as performed by physiotherapists, is to maintain or improve the respira-
tory status of the intubated patient by recruiting poorly aerated alveoli, improving pulmonary compliance and facilitating the removal of excess bronchial secretions, thereby promoting uniform gas distribution and improvement in gas exchange (Novack et al., 1987; Jones et al., 1991; Jones et al., 1992; Webber and Pryor 1998; Maxwell and Ellis, 1998; Denely, 1999). There is a paucity of literature available on the effectiveness of manual hyperinflation as a technique in isolation and only limited reporting on the parameters of manual hyperinflation, such as tidal volume (VT), fraction of delivered oxygen (FDO₂), peak airway pressure (Paw) generated and inflation rate (McCarren and Chow, 1996; McCarren and Chow, 1997; McCarren and Chow, 1998). A recent survey by Hodgson et al. (1999) reported that there was wide variation in the performance of manual hyperinflation and no consensus or guidelines as to best practice for the delivery of manual hyperinflation. There are no published studies investigating operator reliability.

Manual hyperinflation has the potential to cause cardiovascular instability (Conway, 1976; Buchanan and Baun, 1986; Cassidy et al., 1986; Stone et al., 1991a; Stone et al., 1991b; Enright, 1992; Paratz, 1992). The application of manual hyperinflation to acute head injury patients has resulted in increases in mean arterial pressure and intracranial pressure (Crosby and Parsons, 1992; Paratz and Burns, 1993) and may also cause barotrauma or volutrauma to the lung (Dreyfuss et al., 1985; Haake et al., 1987; Dreyfuss et al., 1988).

It has been demonstrated that the different properties of resuscitation circuits and operator technique affect manual hyperinflation (LeBoeuf, 1980; Hess et al., 1989; McCarren and Chow, 1996). To enable repeatability of the beneficial effects, and minimization of potential detrimental effects of manual hyperinflation, investigation is needed into operator reliability or consistency. A description of manual hyperinflation in terms of its parameters and demonstrated repeatability are necessary before valid studies in patients may be conducted. To date there are no published studies reporting therapist consistency in the application of manual hyperinflation.

The aim of the present study was to evaluate the consistency with which individual physiotherapists applied manual hyperinflation to a test lung using a resuscitation circuit with which they were familiar, and to investigate the ability of physiotherapists to modify their manual hyperinflation technique as pulmonary characteristics changed. The study design used was chosen to mimic clinical practice as closely as possible.

**METHOD**

**Subjects**

A quasi-experimental, randomized, repeated-measures study design was used. A convenience sample of 17 physiotherapists was recruited from tertiary teaching hospitals with intensive care facilities within the Perth (Western Australia) metropolitan area. For inclusion in the study, subjects needed a minimum of three months’ continuous experience treating adult mechanically ventilated patients in the preceding year, or one year’s experience in the previous two years if they worked part-time. Written informed consent was obtained from all subjects before the study, and approval was obtained from the Human Ethics Committee of Curtin University of Technology, Western Australia.

**Variables and measurements**

A Vent Aid Training Test Lung, Model 1600 (Michigan Instruments, Grand Rapids, Michigan, USA) was set up, by altering the
compliance ($C_L$) and resistance settings, to simulate three clinical situations commonly encountered in adult intensive care patients, with the assumption of no pre-existing lung pathology:

- ‘Normal’ lungs — (intubated/ventilated) with $C_L$ set at 0.05 litres per centimetre of water (l/cmH$_2$O) and resistance at 2.33 (±0.05) centimetres of water per litre per second (cmH$_2$O/l/s) (Oh, 1990; 681).
- ‘Atelectasis’ of one lung — $C_L$ set at 0.035 l/cmH$_2$O and resistance at 2.33 (±0.05) cmH$_2$O/l/s (Hess and Goff, 1987; 1026).
- ‘Higher than normal’ airway pressure of the lungs mimicking early acute respiratory distress syndrome (ARDS) — $C_L$ set at 0.02 l/cmH$_2$O and resistance at 6.80 (±0.05) cmH$_2$O/l/s (Hess and Goff, 1987; 1026).

These were known as Simulation 1, Simulation 2 and Simulation 3, respectively.

A ‘fast response’ O$_2$ analyser (Beckman Scientific, Model OM11, California, USA) was placed in the test lung to measure the FDO$_2$ from the manual hyperinflation circuit. Initial set-up calibration of the O$_2$ analyser was performed using 100% O$_2$ from a hospital wall supply and room air (assumed to be 21% O$_2$).

The outputs from the pneumotachograph, pressure transducer and O$_2$ analyser were integrated by use of a 16-way Patch box (Medtech Department, SCGH) connected to a termination box (Model TB101, Medtech Department, SCGH) and recorded on an eight-channel strip chart recorder (Model M19, Devices Ltd, Sydney, Australia) with a pen driver amplifier to allow for fine calibration of the deflections. Calibration of all test equipment was performed prior to each subject’s testing session.

**Procedures**

Subjects were informed of the clinical simulation that the test lung was set up to represent but were blind to the specific $C_L$ and resistance settings. Subjects were instructed to perform manual hyperinflation as they would normally perform the technique in the given clinical simulation. No inflation rate was specified and no visual or verbal feedback was provided during testing; the physiotherapists were blind to all of the measurements during the test procedure. Similarly, no simulated mechanical ventilation parameters were discussed or specified as part of the scenario. The manual hyperinflation circuit used by subjects in this study was either the Air-Viva-2 circuit (CIG Health Care, Sydney, Australia), or a Mapleson-B circuit with a two-litre rebreathing bag and an Irwin valve (Kentech, Perth, Australia) in situ, reflecting two types of
manual hyperinflation circuit commonly used (Hodgson et al., 1999). Subjects used the circuit that they would normally encounter in clinical practice. The Air-Viva-2 circuit consists of a silicone rubber self-inflating two-litre bag connected by a flexible neck to a clear non-rebreathing patient valve. It has a reservoir bag attached to the distal end of the bag enabling use without a fresh gas flow. Older models of the Air-Viva-2 circuit have a pressure relief valve that limits the maximum pressure that may be generated to 70 cmH₂O. The model used in this study did not have this valve present.

The Mapleson-B circuit consists of a two-litre reservoir bag connected to an expiratory valve (Irwin valve) via a length of corrugated tubing and depends on a fresh gas flow to fill the bag. The Irwin valve features a spring-loaded plunger that is operated by the thumb and an expiratory flow adjuster.

Oxygen was delivered to the resuscitation circuits at 12 l/min, achieving an FDO₂ of 1.0. After a familiarization period of five breaths, three minutes’ manual hyperinflation was performed for each given simulation. Subjects performed manual hyperinflation for all three simulated situations at the one testing session with a 10-minute rest period between simulations. Subjects, selecting from one of three numbered disks, randomized the order of simulations at each testing session. Three testing sessions (at 0800, 1200 and 1600 hours) occurred over a single day, with repeated measures taken utilizing the same simulated situations. These times were chosen in an attempt to mimic possible physiotherapy treatment times of a patient in an intensive care unit (ICU).

Subjects were tested individually to minimize discussion about the simulations.

**Statistical analyses**

Three minutes of strip chart recordings were obtained from each test period in each clinical simulation. Data collected during the five-breath familiarization period were not included in the analyses. For each manual hyperinflation breath delivered, a value for each of the variables $V_T$, $P_{aw}$ and FDO₂ was recorded from the chart by the investigators. A separate investigator performed verification of a randomly selected sample of the measurements taken from the strip chart. Data were entered onto a Microsoft™ Excel 97 worksheet (Microsoft Corporation). Inflation rate was counted from the strip recording and used to estimate minute volume ($V_M$) ($V_M = \text{mean } V_T \times \text{inflation rate}$).

Both descriptive and inferential statistics were calculated. The mean and standard deviation (SD) was determined for $V_T$, $P_{aw}$ and FDO₂ for individual subjects and the group of all the tests for each simulation. Two-factor analysis of variance (ANOVA) was used to test for differences between the means. Coefficients of variation (Portney and Watkins, 1993) were calculated to investigate the repeatability and accuracy of the manual hyperinflation technique performed. The statistical packages used in data analysis were Microsoft Excel 97 and Super ANOVA (Version 1.11) (Abacus concepts). A probability level of less than 0.05 was taken to represent statistical significance.

**RESULTS**

Seventeen subjects met the inclusion criteria. The data of one subject were excluded due to equipment malfunction at the time of testing. Of the 16 subjects who completed the study, 12 were female. Eight subjects used the Air-Viva-2 circuit and eight used the Mapleson-B circuit, giving two
groups of subjects. All subjects were graduates from Curtin University of Technology School of Physiotherapy, Western Australia, and were employed at one of three metropolitan tertiary teaching hospitals. Experience of working in an ICU ranged from four months to six years (mean duration 16 months).

All subjects used a two-handed manual hyperinflation technique. However, those subjects using the Air-Viva-2 circuit squeezed the bag with both hands, whereas those using the Mapleson-B circuit used one hand to squeeze the reservoir bag and the other to operate the Irwin valve. By examining the traces it was noted that none of the subjects using the Air-Viva-2 circuit incorporated a pause at the end of inspiration and no positive end expiratory pressure (PEEP) was generated. However, all the subjects in the Mapleson-B group incorporated a brief pause at the end of inspiration and PEEP ranging from 0 cmH\textsubscript{2}O to 10 cmH\textsubscript{2}O was generated.

Data for both groups for $V_T$, $P_{aw}$, FDO\textsubscript{2}, inflation rate and $V_M$ for each simulation are presented in Table 1.

The trend in the data was the same, irrespective of the circuit used. Tidal volume was significantly lower in Simulation 3 compared to simulations 1 or 2 ($p < 0.001$) with no significant differences between the three tests in the Air-Viva-2 group ($p = 0.724$), or the Mapleson-B group ($p = 0.493$). Mean $V_T$ for each test tended to be higher in the Mapleson-B group (range 508–2360 ml) than in the Air-Viva-2 group (range 262–1246 ml). Peak airway pressure

<table>
<thead>
<tr>
<th>TABLE 1: Descriptive data of the dependent variables resulting from the manual hyperinflation technique according to circuit used</th>
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<tr>
<td><strong>Variable (SD)</strong></td>
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<tr>
<td>Tidal volume ($V_T$) (ml)</td>
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<tr>
<td>Peak airway pressure ($P_{aw}$) (cmH\textsubscript{2}O)</td>
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<tr>
<td>Fraction of delivered oxygen (FDO\textsubscript{2})</td>
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<tr>
<td>Inflation rate (i/min)</td>
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<tr>
<td>Minute volume ($V_M$) (l/min)</td>
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Values are means and standard deviations (SD).
*Represents a significant difference in Simulation 3 compared to Simulation 1 or 2 ($p < 0.001$).
SD = standard deviation; ml = millilitre; l/min = litres per minute; cmH\textsubscript{2}O = centimetres of water
i/min = inflations per minute.
was significantly higher in Simulation 3 compared to simulations 1 or 2 ($p < 0.001$) in both groups, with no significant difference between the three tests in the Air-Viva-2 group ($p = 0.963$) or the Mapleson-B group ($p = 0.125$). Again, mean $P_{aw}$ tended to be higher in the Mapleson-B group (range 21–50 cmH$_2$O) than in the Air-Viva-2 group (range 4–30 cmH$_2$O).

For each simulation, mean values for $FDO_2$ ranged from 0.63 to 0.93 in the Air-Viva-2 group with only three subjects consistently delivering greater than 0.8 $FDO_2$ during the tests for all three simulations. In the Mapleson-B group mean values for $FDO_2$ ranged from 0.87 to 0.98, with all subjects consistently delivering greater than 0.85 $FDO_2$ during all tests for all simulations.

There was no significant difference in inflation rate between simulations in the Air-Viva-2 group ($p = 0.289$) or the Mapleson-B group ($p = 0.340$) or between tests in the Air-Viva-2 group ($p = 0.491$) or the Mapleson-B group ($p = 0.592$). Corresponding to the trend observed in the data for $V_T$, in both groups $V_M$ was significantly lower in Simulation 3 compared to simulations 1 or 2 ($p < 0.001$) with no significant difference between test in the Air-Viva-2 group ($p = 0.695$) or the Mapleson-B group ($p = 0.206$). Coefficients of variation for inter-therapist reliability for all variables are presented in Table 2.

**DISCUSSION**

The present study investigated consistency in the performance of manual hyperinflation in terms of $V_T$, $P_{aw}$, $FDO_2$, inflation rate and $V_M$ as applied by physiotherapists to a test lung. The low values of coefficients of variation (that is, < 10%) for $V_T$, $P_{aw}$ and $FDO_2$ for all three simulations suggest good reliability by both the Air-Viva-2 and Mapleson-B groups. However, closer inter-

<table>
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<tr>
<th>Variable</th>
<th>Air-Viva ($n = 8$)</th>
<th>Mapleson-B ($n = 8$)</th>
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<tr>
<td>Tidal volume ($V_t$)</td>
<td>8.7</td>
<td>6.2</td>
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<tr>
<td>Range of individual values</td>
<td>2.4–51.0</td>
<td>2.3–10.4</td>
</tr>
<tr>
<td>Peak airway pressure ($P_{aw}$)</td>
<td>9.9</td>
<td>6.5</td>
</tr>
<tr>
<td>Range of individual values</td>
<td>2.4–49.1</td>
<td>3.3–12.4</td>
</tr>
<tr>
<td>Fraction of delivered oxygen ($FDO_2$)</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td>Range of individual values</td>
<td>0.0–2.2</td>
<td>0.0–0.9</td>
</tr>
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</table>

Values are percentages

$$CV = \frac{SD}{\bar{x}} \times 100$$

$CV = \text{coefficient of variation}; SD = \text{standard deviation}; \bar{x} = \text{mean}$ (Portney and Watkins, 1993; 646).
interpretation of coefficients of variation values is necessary to ascertain possible clinical implications. Although the coefficients of variation for \( FDO_2 \) in the Air-Viva-2 group were low (<10%), indicating subjects were consistent in the amount of oxygen they delivered to the test lung, five of the eight subjects repeatedly delivered less than 0.8 \( FDO_2 \) during all tests for all simulations. Conversely, coefficients of variation for \( FDO_2 \) of the Mapleson-B group were also low (<10%), indicating good reliability, but all subjects delivered greater than 0.85 \( FDO_2 \). Similarly, when interpreting the coefficients of variation for the other variables it is important to recognize that, although the subjects may have demonstrated good reliability when inflating the test lung, the actual values of these variables may not be appropriate during manual hyperinflation of a patient. For instance, consistently high \( V_M \) during manual hyperinflation may result in a decreased level of arterial carbon dioxide causing decreased respiratory drive in a patient required to take spontaneous breaths and consistently high values of \( V_T \) and \( P_{aw} \) would place the patient at risk of pulmonary volutrauma and barotrauma.

Although the delivery of a larger \( V_T \) by manual hyperinflation has been recommended to reinflate atelectatic lung tissue and improve \( C_L \) (Jones et al., 1992; Webber and Pryor, 1998), all subjects in the present study modified their technique of manual hyperinflation appropriately as the test lung airway resistance increased and \( C_L \) decreased. There was significant reduction in \( V_T \) in Simulation 3 compared to simulations 1 and 2 in both groups that would lessen the risk of pulmonary volutrauma. However, in the Mapleson-B group \( V_T \) was higher than that of the Air-Viva-2 group with some subjects delivering up to 2360 ml per inflation. Although the reservoir bag in the Mapleson-B circuit is a standard two-litre anaesthetic bag, it is possible to achieve a higher volume by holding the expiratory valve in the circuit in the closed position allowing continuous filling of gas into the lung (this will occur as long as the resistance to flow in the airway is less than in the resuscitation circuit). In both groups there were significant increases in \( P_{aw} \) as resistance increased and \( C_L \) decreased. In the Air-Viva-2 group the mean \( P_{aw} \) for Simulation 3 was only 21.4 cmH\(_2O\), as compared to 41.9 cmH\(_2O\) in the Mapleson-B group with three subjects in particular regularly generating a \( P_{aw} \) of 50 cmH\(_2O\) per inflation. It is a long-standing and widely held belief that \( P_{aw} \) greater than 40 cmH\(_2O\) is associated with increased incidence of pulmonary barotrauma in mechanically ventilated patients (Kumar et al., 1973; Peterson and Baier, 1983; Haake et al., 1987; Marcy, 1993; Slutsky, 1994). It has also been demonstrated that inflation pressures greater than 45–50 cmH\(_2O\) result in pulmonary oedema in rats (Dreyfuss et al., 1985; Dreyfuss et al., 1988). However, Leatherman et al. (1989) reported no cases of pulmonary barotraumas in mechanically ventilated patients with asthma despite \( P_{aw} \) values as high as 110 cmH\(_2O\) and an average \( P_{aw} \) of 68 cmH\(_2O\). Recent evidence indicates that high \( P_{aw} \) is not in itself injurious to the lung. Rather, over-distension of the lung appears to be the fundamental mechanism, with \( P_{aw} \) sometimes acting as a marker, but end inspiratory lung volume being a better predictor of lung injury (Egan, 1982; Tuxen and Lane, 1987; Dreyfuss and Saumon, 1992; Williams et al., 1992; Parker et al., 1993; Manning, 1994). More specifically, damage may be attributed to the over-distension of the lung that is already of reduced volume due to pathology (Burchard and Sydow, 1994). Thus, the higher \( P_{aw} \) values with the Mapleson-B circuit may not be of as much concern as the
higher $V_T$ recorded. As yet, there has been no clear consensus in the literature as to a ‘safe’ volume during manual hyperinflation in terms of preventing volutrauma. Mechanically ventilated patients with increased airway resistance and decreased $C_L$ have a high risk of pulmonary volutrauma from alveolar overdistension (Gammon et al., 1992; Gammon et al., 1995). Successful mechanical ventilation of these patients at a lower than normally recommended $V_T$ has been reported (Lee et al., 1990; Kiisui et al., 1992). Although in this respect the Air-Viva-2 circuit may appear safer, it should be noted that occasional $V_T$ values as low as 262 ml were recorded with this circuit which could result in hypoventilation in a patient and certainly would not achieve hyperinflation.

Unlike previous studies (Chulay, 1988; Stone et al., 1989; Corley et al., 1993; Eales et al., 1995; Ntoumenopoulos et al., 1998) subjects were not instructed to perform manual hyperinflation at a particular rate, as inflation rate was a dependent variable. Examination of results for the dependent variables revealed only small differences between tests. This suggested good intra-therapist constancy and is confirmed with the findings of a low coefficient of variation. Only one subject in the Air-Viva-2 group showed some inconsistency from test to test.

Although standardization of the technique is important to enable repeatability of its beneficial effects and minimization of any detrimental effects, the present study and the work of McCarren and Chow (1996) demonstrate that the type of resuscitation circuit used influences manual hyperinflation. The technique of pausing at full inspiration to allow for continuous filling of gas into the lung, as may occur with the Mapleson-B circuit, is advocated by Ntoumenopoulos et al. (1998) and Webber and Pryor (1998) to enhance collateral ventilation with the aim of recruiting poorly aerated alveoli. None of the subjects using the Air-Viva-2 circuit were observed to incorporate a prolonged end inspiratory pause in their technique as the non-rebreathing expiratory valve has been designed to allow gas to leak, preventing an excessive increase of volume and airway pressure, thereby minimizing the risk of pulmonary barotrauma and volutrauma. It is not possible to close this valve in the way that it is possible to close the Irwin valve.

In contrast to the Mapleson-B circuit, it is not possible to apply PEEP whilst using the Air-Viva-2 circuit without the incorporation of a separate Draeger valve and PEEP valve within the circuit. The application of PEEP during mechanical ventilation is often used in an effort to recruit poorly aerated alveoli and to prevent airway closure at end expiration by increasing functional residual capacity (Benito and Lemaire, 1990; Marcy and Marini, 1991). When treating a patient who is artificially ventilated with PEEP it is important to maintain this PEEP during manual hyperinflation to prevent deterioration in respiratory status. Results from the present study show that it is possible to maintain up to 10 cmH₂O of PEEP with the Mapleson-B circuit without the inclusion of a separate valve.

Hyper-oxygenation, via manual hyperinflation, is commonly used before suctioning to prevent decreases in arterial oxygenation, a practice well supported by the literature (Goodnough, 1985; Chulay, 1988; Eales, 1989; Stone et al., 1989; Stone, 1990; Dam et al., 1994). Also, the combination of reinflation of atelectatic lung tissue and hyper-oxygenation should support the use of manual hyperinflation in improving gas exchange by improving ventilation/perfusion matching. To achieve these goals a flow rate of 10–15 l/min is recommended to achieve a FDO₂ of 1.0 to the circuit (Chulay,
1988; Jones et al., 1991; Webber and Pryor, 1998), and a FiO₂ of at least 0.8 (Eaton, 1984). Studies evaluating manual hyperinflation circuits have demonstrated FiO₂ to vary by as much as 0.3–1.0 at a flow rate of 15 l/min (Barnes and Watson, 1982; Barnes and Watson, 1983; Eaton, 1984; Corley et al., 1993). Performance data of the Air-Viva-2 circuit in particular are extremely scarce. Phillips and Skowronski (1986) state that the achievable FiO₂ with an Air-Viva circuit is 0.98. The Laerdal resuscitation circuit is similar and achieves a FiO₂ of 0.88–1.0 (Eaton, 1984). However, the results of studies on other resuscitation circuits should not be generalized to the Air-Viva-2 circuit. Operator technique must also be considered as a possible explanation for the unexpectedly low FDO₂ values observed in the present study. Operator hand size is known to affect FiO₂ during manual hyperinflation with lower FiO₂ being delivered by operators with small hands (Law, 1982). A fast inflation rate that does not allow the reservoir bag to fill adequately also reduces FiO₂ (Eaton, 1984; Glass et al., 1993) and is a possible explanation for the low FDO₂ values obtained in the Air-Viva-2 group. These results suggest that patients requiring 0.8 or greater FiO₂ should not receive manual hyperinflation with this circuit without further investigation into its capacity to deliver high values of FiO₂.

There are obvious limitations to the present study. As well as quasi-experimental design with the use of a convenience sample of small size, the study was performed on a test lung and, although this equipment has been used extensively without criticism of its reliability or validity (Hess and Goff, 1987; Hess et al., 1989; Hess et al., 1993; Hess and Spahr, 1990; McCarren and Chow, 1996), the results obtained using a test lung should not be generalized to patients. Airway resistance and C_L in a test lung is fixed, whereas in patients these variables are likely to change with the type of mechanical ventilation, body position, lung pathology and throughout physiotherapeutic intervention. Also, the findings of two resuscitation circuits should not be generalized to other circuits. Operator technique in the application of manual hyperinflation may vary between circuits but may still be safe and effective. In the present study, using two types of resuscitation circuit, all subjects demonstrated modification of their technique in response to changes in C_L and airway resistance. However, clinically there are other reasons why manual hyperinflation might be modified, such as raised intracranial pressure, risk of over-inflation or bronchospasm. It is not possible to simulate such factors and therefore the present study differs from the clinical situation.

Before studies are conducted on patients it is suggested that further research be undertaken on the test lung investigating the oxygen delivery capabilities of the Air-Viva-2 resuscitation circuit, and methods of manual hyperinflation that avoid high levels of P_{aw} and V_{t} whilst using the Mapleson-B circuit with the Irwin valve. Also, the present study should be repeated with larger sample sizes using different resuscitation circuits and different subject groups, such as less-experienced physiotherapists and nurses, to gain further description and definition of techniques and more information on operator reliability.

CONCLUSION

In the present study, physiotherapists appropriately modified the technique of manual hyperinflation, as applied to a test lung using the Air-Viva-2 resuscitation circuit and the Mapleson-B (with Irwin valve) resuscitation circuit, in response to changes
in airway resistance and $C_L$, and demonstrated good reliability and consistency in doing so. This study has allowed further description of manual hyperinflation, which is very clearly influenced by the circuit used. Fraction of delivered oxygen was less than 0.80 in five out of eight subjects who used the Air-Viva-2 circuit, which is lower than expected, has implications for clinical practice, and warrants further investigation. The potential to generate high $P_{aw}$ and $V_T$ whilst using the Mapleson-B circuit with the Irwin valve in situ also has implications for clinical practice. Further research is recommended to evaluate other resuscitation circuits and the reliability of different subject groups before conducting studies in patients.

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