The effect of circuit type, volume delivered and “rapid release” on flow rates during manual hyperinflation

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Traditionally, manual hyperinflation has been performed using “rapid release” to promote a fast peak expiratory flow rate (PEFR) but rapid release has not been described. In addition, it has been demonstrated that different resuscitation circuits provide varying degrees of resistance to expiratory flow and it is known that a variety of circuits are used in Australia for manual hyperinflation. The aim of this study was to document current practice, the effect of rapid release, controlling inspiration, different volumes and circuit type on flow rates, and the inspiratory to expiratory flow rate (I:E) ratio during manual hyperinflation. Using a test lung model, 15 physiotherapists performed 11 trials using the Air Viva 2, a Mapleson-C and a Mapleson-F circuit, both with and without rapid release, and delivering two volumes. The order of the trials was randomised. Rapid release produced a faster PEFR irrespective of circuit type or volume delivered. The effect of rapid release, and the absolute PEFR, was less for the Air Viva 2 compared with the Mapleson circuits. Expiratory flow rate was faster for the larger volume. The theoretically optimal I:E ratio to move secretions was achieved delivering the lower target volume with the Mapleson circuits and using rapid release. [Maxwell LJ and Ellis ER (2003): The effect of circuit type, volume delivered and “rapid release” on flow rates during manual hyperinflation. Australian Journal of Physiotherapy 49: 31-38]

Key words: Intensive Care; Pulmonary Ventilation; Physical Therapy; Respiration, Artificial

Introduction

Manual hyperinflation is the technique of applying a larger than tidal volume breath using a resuscitation circuit. Recent surveys show that physiotherapists use manual hyperinflation as a secretion clearance technique (Hodgson et al 1999, King and Morrell 1992) and it is thought this is achieved by simulating a cough (Hack et al 1980, Hodgson et al 1996, MacLean et al 1989). A review of the literature reporting flow rates generated during manual hyperinflation found that manual hyperinflation did not produce expiratory flow rates of the magnitude of cough (Maxwell and Ellis 1998). These authors proposed however, that clearance of secretions may still occur with manual hyperinflation through the generation of annular two-phase gas-liquid flow. For any liquid there is a critical gas flow rate that must be met before it will move. The key to movement of secretions by two-phase gas-liquid flow is the relationship between inspiratory and expiratory flow. To achieve net movement in one direction of a viscoelastic liquid such as mucus, when the gas movement is bi-directional, the inspiratory flow rate must be at least 10% slower than the critical expiratory flow rate, that is an inspiratory to expiratory flow rate (I:E) ratio of less than or equal to 0.9 (Kim et al 1985).

A number of factors could influence flow rates and therefore the I:E ratio during manual hyperinflation. Some are outside the direct control of the physiotherapist, for example the diameter of the endotracheal tube and the patient’s pulmonary pathology. Others, such as operator performance (the rate and amount of bag compression during inspiration and handling of the circuit during expiration) and the type of resuscitation circuit used can potentially be influenced by the physiotherapist.

Although manual hyperinflation has been shown to enhance secretion clearance (Hodgson et al 2000) the exact application of the technique for this purpose has not been described. Also, a variety of circuits are used in Australia (Hodgson et al 1999) and it is not known if the circuit type influences flow ratios when the performance of manual hyperinflation is standardised. Inspiratory and expiratory flow rates generated during manual hyperinflation using a Mapleson-C circuit with a CIG spring-loaded valve have been reported by Maxwell and Ellis (2002). They demonstrated that the degree of valve closure influenced gas flow rates. The effect of other circuit types or configurations on flow rates during manual hyperinflation has not been described.

The original description of manual hyperinflation included the technique (operator performance) of “rapid release” to increase expiratory flow rate (Clement and Hübsch 1968). The performance of rapid release and the effect on expiratory flow rate has not been described.

The aims of this study were to:
1. describe volume delivered, peak inspiratory flow rate (PIFR) and peak expiratory flow rate (PEFR) when manual hyperinflation is used to enhance secretion clearance as per current practice;
2. report the effect of rapid release, controlling
inspiratory time and volume delivered on inspiratory and expiratory flow rates, with three resuscitation circuits used for manual hyperinflation in Australia; and

3. compare the I:E ratio to those previously identified to produce movement of mucus simulants by annular two-phase gas-liquid flow.

Methods and materials

A randomised 3 x 2 x 2 within-subjects repeated measures design was used. The factors were circuit type (Mapleson vs Air Viva 2), release technique and volume delivered. Subjects were recruited through flyers sent to principal referral and major metropolitan hospitals in New South Wales (NSW Health 1998) and posted on noticeboards at the School of Physiotherapy, The University of Sydney. Subjects were eligible to participate in the study if they were experienced cardiothoracic physiotherapists or had used manual hyperinflation in the previous 12 months. The term “experienced cardiothoracic physiotherapists” was not defined specifically, but was used so that subjects who had used manual hyperinflation regularly in the past, but may not have been in clinical practice in the last 12 months, were eligible to participate. All subjects received an information sheet and signed a consent form. Ethics approval was obtained from the Human Ethics Committee of The University of Sydney.

Subjects completed a questionnaire to obtain information about their experience since graduation, use and technique of manual hyperinflation. They then performed 11 2 min trials of manual hyperinflation. For the first trial (Choice Trial) subjects selected the bagging circuit of their choice and performed manual hyperinflation as they would if aiming to enhance secretion removal. The subjects then performed the other 10 trials (Standardised Trials).

With each of the three circuits the subjects delivered a volume of 1.4 litres, both with and without rapid release technique (six trials). The technique of rapid release was described to the subjects as performing manual hyperinflation to achieve a fast expiratory flow. No instruction as to how to perform expiration was given except to either perform the bag/valve release as they would if they were not concerned about secretions (slow release) or rapid release to enhance secretion removal. Subjects were informed that if they always performed the technique to clear secretions, they did not need to change their technique for the slow trials.

The target volume of 1.4 litres was chosen to allow comparison between the different circuits and was based on two previous studies showing that, in a test lung model, physiotherapists deliver somewhere between 1.3 (McCarren and Chow 1996) and 1.5 litres (Rusterholz and Ellis 1998) with the Air Viva 2. In addition, with the Mapleson circuits, the subjects were asked to empty the bag on inspiration again with and without rapid release technique to assess the effect of volume on flow rates (four trials, Figure 1). The term “empty the bag” was used rather...
than a litre target volume as with Mapleson circuits, volume delivered can exceed bag capacity (Maxwell and Ellis 2002). For all 10 Standardised Trials, inspiration was performed over three seconds to the beat of a metronome (based on the original description of the technique by Clement and Hübsch 1968).

For the Standardised Trials, 24 different order combinations of circuit type, volume delivered and release technique were designed and each combination was recorded on a card and placed in a sealed envelope. When they arrived for the study, subjects randomly drew an envelope that was not replaced. Subjects were given time to familiarise themselves with the equipment, using their circuit of choice prior to the first trial. For all subsequent trials, subjects were also given time to practise with the circuits and delivering the two target volumes of 1.4 litres and emptying the bag. Subjects were allowed to rest for as long as they wished between each trial.

The resuscitation circuits used were the CIG Air Viva 2, which is a Laerdal-style circuit; a Mapleson-C circuit with a spring loaded exhale valve (CIG Medishield CIGDF655) and a 2 L antistatic re-breathing bag (Ohmeda, Ref 372762); and a Mapleson-F circuit consisting of an elbow connector with oxygen port connected to a length of wide bore tubing and a 2 L anti-static re-breathing bag with the end loop removed (Figure 2). The Air Viva circuit was used as a self-inflating circuit without the reservoir bag. The flow rate from the air cylinder to the Mapleson circuits was set at 12 L/min.

The bagging circuit was connected in series to the pneumotachometer (Hans Rudolph Inc., Kansas City) and the test lung (Vent Aid ‘TTL Test Training Lung’, Michigan Instruments Inc.). For this study the compliance of the “lung” was set at 0.05 L/cmH2O, and the resistance of the “trachea” and “main bronchi” was 2.33 +/-5% cmH2O at a flow rate of 1.0 L/sec. To assist subjects in delivering 1.4 litres for those particular trials, the 700 mL mark was clearly marked on the centre of the test lung volume panel (700 mL per “lung” equalling a total volume delivered of 1.4 litres).

A custom-designed data acquisition and analysis system,

Table 1. Individual subject’s background, circuit experience, reported inspiratory time and use of rapid release as reported on the questionnaire.

<table>
<thead>
<tr>
<th>Years since Graduation</th>
<th>Current Employment</th>
<th>Experience with, and circuit of choice</th>
<th>Reported Ti (seconds)</th>
<th>Do you ever choose not to use rapid release?</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Academic</td>
<td>N</td>
<td>Y 4 years</td>
<td>Y</td>
</tr>
<tr>
<td>23</td>
<td>Academic</td>
<td>Y 12 years</td>
<td>N</td>
<td>3</td>
</tr>
<tr>
<td>12</td>
<td>Academic</td>
<td>Y 3 years</td>
<td>N</td>
<td>Y 2 years</td>
</tr>
<tr>
<td>12</td>
<td>Research</td>
<td>Y 5 years</td>
<td>N</td>
<td>Y 3 years</td>
</tr>
<tr>
<td>12</td>
<td>Research</td>
<td>Y W/E 1 year</td>
<td>Y 2 years</td>
<td>Y W/E 1 year</td>
</tr>
<tr>
<td>22</td>
<td>Hospital</td>
<td>Y 6 years</td>
<td>N</td>
<td>Y 3 years</td>
</tr>
<tr>
<td>12</td>
<td>Hospital</td>
<td>Y 12 years</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>7</td>
<td>Hospital</td>
<td>Y 3 years</td>
<td>Y 6 years</td>
<td>N</td>
</tr>
<tr>
<td>7</td>
<td>Hospital</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>6</td>
<td>Hospital</td>
<td>Y 2 years</td>
<td>N</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Hospital</td>
<td>Y 3 years</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>3</td>
<td>Hospital</td>
<td>Y 2 years</td>
<td>N</td>
<td>Y 6 months</td>
</tr>
<tr>
<td>2</td>
<td>Hospital</td>
<td>Y 4 months</td>
<td>N</td>
<td>3</td>
</tr>
<tr>
<td>1.5</td>
<td>Hospital</td>
<td>Y 1 month</td>
<td>Y 1 month</td>
<td>N</td>
</tr>
<tr>
<td>1.5</td>
<td>Hospital</td>
<td>N</td>
<td>N</td>
<td>Y 1 year</td>
</tr>
</tbody>
</table>

Bolded data identify circuit of choice (Y = yes, N = no, W/E = weekend work, nr = not recorded, Ti = inspiratory time).

Table 2. Mean (SD), minimum, maximum and range for volume delivered, PIFR, PEFR and I:E ratio for the Choice Trial.

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (L)</td>
<td>1.68 (0.27)</td>
<td>1.38</td>
<td>2.39</td>
<td>1.01</td>
</tr>
<tr>
<td>PIFR (L/s)</td>
<td>1.71 (0.67)</td>
<td>0.72</td>
<td>2.89</td>
<td>2.17</td>
</tr>
<tr>
<td>PEFR (L/s)</td>
<td>1.99 (0.31)</td>
<td>1.61</td>
<td>2.53</td>
<td>0.92</td>
</tr>
<tr>
<td>I:E ratio</td>
<td>0.89 (0.01)</td>
<td>0.39</td>
<td>1.62</td>
<td>1.23</td>
</tr>
</tbody>
</table>

PIFR = peak inspiratory flow rate, PEFR = peak expiratory flow rate, I:E = inspiratory to expiratory flow rate ratio

than a litre target volume as with Mapleson circuits, volume delivered can exceed bag capacity (Maxwell and Ellis 2002). For all 10 Standardised Trials, inspiration was performed over three seconds to the beat of a metronome (based on the original description of the technique by Clement and Hübsch 1968).

For the Standardised Trials, 24 different order combinations of circuit type, volume delivered and release technique were designed and each combination was recorded on a card and placed in a sealed envelope. When they arrived for the study, subjects randomly drew an envelope that was not replaced. Subjects were given time to familiarise themselves with the equipment, using their circuit of choice prior to the first trial. For all subsequent trials, subjects were also given time to practise with the circuits and delivering the two target volumes of 1.4 litres and emptying the bag. Subjects were allowed to rest for as long as they wished between each trial.

The resuscitation circuits used were the CIG Air Viva 2, which is a Laerdal-style circuit; a Mapleson-C circuit with a spring loaded exhale valve (CIG Medishield CIGDF655) and a 2 L antistatic re-breathing bag (Ohmeda, Ref 372762); and a Mapleson-F circuit consisting of an elbow connector with oxygen port connected to a length of wide bore tubing and a 2 L anti-static re-breathing bag with the end loop removed (Figure 2). The Air Viva circuit was used as a self-inflating circuit without the reservoir bag. The flow rate from the air cylinder to the Mapleson circuits was set at 12 L/min.

The bagging circuit was connected in series to the pneumotachometer (Hans Rudolph Inc., Kansas City) and the test lung (Vent Aid ‘TTL Test Training Lung’, Michigan Instruments Inc.). For this study the compliance of the “lung” was set at 0.05 L/cmH2O, and the resistance of the “trachea” and “main bronchi” was 2.33 +/-5% cmH2O at a flow rate of 1.0 L/sec. To assist subjects in delivering 1.4 litres for those particular trials, the 700 mL mark was clearly marked on the centre of the test lung volume panel (700 mL per “lung” equalling a total volume delivered of 1.4 litres).

A custom-designed data acquisition and analysis system,
Table 3. Comparison of flow rates for the Choice Trial for the same circuit type with Standardised Trials using rapid release for the same circuit type at an equivalent volume [mean (SD)].

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Choice Trial mean (SD)</th>
<th>Rapid release for Standardised Trials n = 15, mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Volume (L)</td>
<td>PIFR (L/s)</td>
</tr>
<tr>
<td>AV n = 7</td>
<td>1.49 (0.10)</td>
<td>2.03 (0.54)</td>
</tr>
<tr>
<td>MC n = 2</td>
<td>1.67 (0.09)</td>
<td>1.27 (0.03)</td>
</tr>
<tr>
<td>MF n = 6</td>
<td>1.93 (0.25)</td>
<td>1.48 (0.78)</td>
</tr>
</tbody>
</table>

|         | Empty the bag | 2.06 (0.31) |
|         | PIFR (L/s) | PEFR (L/s) | PIFR (L/s) | PEFR (L/s) |
| AV = Air Viva 2, MC = Mapleson-C, MF = Mapleson-F, n = number of subjects choosing that circuit in Choice Trial, # = mean (SD) for volume delivered for all Standardised Trials at that target volume.

the accuracy and reliability of which has been reported previously, was used for this study (Maxwell et al 2001). The signal from the pneumotachometer was recorded by the data acquisition system. The analysis system then calculated the volume delivered and recorded the PIFR and PEFR. The I:E ratio was then calculated manually.

The results for the Choice Trial are reported using descriptive statistics and are shown as mean (SD). For the Standardised Trials, volume delivered, inspiratory and expiratory flow and the I:E ratio were analysed using repeated measures ANOVA with planned contrasts (Winer et al 1991) to test for the effects of circuit type, release technique, volume delivered and any interactions between these factors, and are reported as mean (SEM). At the target volume of 1.4 litres there were minimal differences between the Mapleson-C and Mapleson F circuits for the variables measured, therefore the mean result for the Mapleson circuits is compared with those of the Air Viva 2.

### Results

**Questionnaire** The 15 subjects included three academic staff recruited from The University of Sydney, two graduate research students and 10 clinical educators or clinicians representing seven different hospitals. Five subjects were male and the period since graduation, experience with different circuits and reported inspiratory time is shown in Table 1. All subjects described their technique as consisting of a slow inspiratory phase and six indicated that they did not always use rapid release. Reasons for not using rapid release were haemodynamic instability, treatment aim was volume restoration, not wanting to cause a cough/excessive coughing and small inspiratory volume making rapid release ineffective.

**Choice Trial** The mean volume delivered, PIFR and PEFR generated by each subject in the Choice Trial varied considerably and PIFR was more variable than PEFR (Table 2 and Figure 3A). Five subjects produced a PIFR faster than PEFR and nine produced an I:E ratio of greater than 0.9 (Figure 3B). There were no obvious trends with years since graduation.

**Standardised Trials**

- **Effect of rapid release** Peak expiratory flow rate was faster using rapid release and this was statistically significant for all trials, irrespective of circuit type or target volume (1.4 litres, $p < 0.003$; empty the bag, $p = 0.005$). The increase in PEFR using rapid release was greater for the Mapleson circuits compared with the Air Viva 2, (0.17 vs 0.09 L/sec, $p = 0.05$). Unexpectedly rapid release produced an increase in PIFR for the Mapleson circuits (0.04 L/sec, $p = 0.02$), and the increase was greater for the Mapleson-F compared with the Mapleson-C (0.07 vs 0.02 L/sec, $p = 0.007$).

- **Effect of volume delivered** The difference between the two target volumes for the Mapleson circuits was significant (1.47 (0.03) vs 2.06 (0.04) litres, $p < 0.001$). Both PIFR and PEFR for the Mapleson circuits at the 1.4 L target was slower than emptying the bag (0.99 (0.03) vs 1.37 (0.03) L/sec, $p < 0.001$ and 1.83 (0.03) vs 2.19 (0.04) L/sec, $p < 0.001$ respectively, Figure 4A).

- **Effect of circuit type** There was no significant difference in the volume delivered at the target of 1.4 litres between the Air Viva 2, Mapleson-C and Mapleson-F circuits (1.40 (0.04), 1.46 (0.03) 1.47 (0.04) respectively, $p = 0.06$). The difference between the Mapleson-C and Mapleson-F circuits for emptying the bag was also not significant (2.02 (0.07), 2.11 (0.09) respectively, $p = 0.15$). Peak inspiratory flow rate was faster with the Air Viva 2 compared with the Mapleson circuits (1.15 (0.05) vs 0.99 (0.03) L/sec, $p = 0.006$), whereas PEFR was significantly slower for the Air Viva 2 compared with the Mapleson circuits (1.65 (0.03) vs 1.90 (0.05) L/sec, $p < 0.001$). None of the subjects maintained bag compression during expiration when using the Mapleson-C.

**The I:E ratio** The mean I:E ratio was less than 0.9 for all Standardised Trials irrespective of release technique, volume delivered or circuit type (Figure 4B). Rapid release resulted in statistically significant reduction in the I:E ratio for all three circuits at the target volume of 1.4 litres ($p = 0.03$) however, when emptying the bag for the Mapleson circuits, the difference between slow and rapid release was not significant ($p = 0.07$). When using rapid...
release the I:E ratio was 0.52 for the mean of the Mapleson circuits at the target 1.4 litres, 0.71 for the Air Viva 2 and 0.61 for the mean of emptying the bag for the Mapleson circuits. The differences were statistically significant between the Air Viva 2 and Mapleson circuits at 1.4 litres ($p < 0.001$), and between the two volumes for the Mapleson circuits ($p < 0.001$).

**Comparison of Choice Trial with Standardised Trials** As can be seen in Figure 3A, the PEFR generated by individual physiotherapists using the same circuit type in the Choice Trial was similar, but PIFR was variable. If volume is taken into account, comparing the Choice Trial with the Standardised Trials, the mean PEFR for each circuit type was similar but the mean PIFR was faster for the Choice Trial (Table 3).

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**Figure 3.** Flow rates measured and calculated the I:E ratio when individual subjects used their circuit and technique of choice to clear secretions. A: PIFR and PEFR for each individual subject, mean (SD). B: I:E flow rate ratio for each individual subject. Labels on the ‘x’ ordinate indicate circuit of choice. The dashed line in B represents an I:E ratio of 0.9. (AV = Air Viva 2, MC = Mapleson-C, MF = Mapleson-F, PIFR = peak inspiratory flow rate, PEFR = peak expiratory flow rate, I:E = inspiratory to expiratory flow rate ratio).
Discussion

This study is the first to document PIFR, PEFR and volume delivered when physiotherapists are asked to apply manual hyperinflation with the aim of enhancing secretion clearance, and to report the effect of the technique of rapid release in a test lung model. This study concurs with the findings of Hodgson et al (1999) that different circuit types are used in Australia for manual hyperinflation. The findings of this study indicate that there may be considerable variability in current practice in terms of flow rates generated, in particular PIFR, and therefore I:E ratio when manual hyperinflation is used with the aim to enhance secretion clearance. The technique of rapid release does produce a faster expiratory flow rate and, when inspiratory time is controlled, the theoretical I:E ratio to produce annular two-phase gas-liquid flow can be met irrespective of circuit type. Circuit type can, however, influence the ratio.

The technique of manual hyperinflation as originally described by Clement and Hubsch (1968) included an inspiratory time of three seconds and rapid release of the bag to obtain a fast expiratory flow rate to help move secretions. There was considerable variability between subjects in the Choice Trial for preferred circuit and performance of manual hyperinflation in this study. The variability in performance was greater for the PIFRs generated compared with the PEFRs. This finding of variability in inspiratory flow rate in current practice is supported by the results of the questionnaire where subjects described performing manual hyperinflation with an inspiratory time of between one-and-a-half and five seconds. When comparing the PIFR for the Choice Trial, with those of the Standardised Trials, at a roughly equivalent volume, PIFR was faster for the Choice Trial therefore inspiratory time must have been less than three seconds.

The above finding suggests that physiotherapists may not regulate inspiratory flow rate sufficiently and is supported by a study by Thomas and Wong (1996). These authors reported an inspiratory flow rate of 1.69 L/sec when physiotherapists performed manual hyperinflation as per their current practice in a test lung model. After instruction to perform inspiration over three seconds, inspiratory flow rate was 0.95 L/sec, a decrease of 0.73 L/sec. Unfortunately, the authors did not indicate whether they measured PIFR or calculated mean inspiratory flow rate and, as the technique included an inspiratory hold, the interpretation of this finding is unclear.

It must be acknowledged that the suggestion that physiotherapists perhaps do not regulate inspiratory flow rate may not be entirely true in the clinical setting. Manning et al (1995) demonstrated that intubated and ventilated normal subjects had a preferred inspiratory flow rate and flow rates above or below this produced a sensation of discomfort. Slower inspiratory flow rates were more uncomfortable than faster flow rates. Unlike expiratory flow rate during manual hyperinflation, which is often not influenced by the patient’s response, physiotherapists may alter their inspiratory technique and therefore inspiratory flow rate in response to perceptions of the patient’s degree of comfort. In a test lung model there is no feedback, therefore PIFR and the impact of this on I:E ratio in the clinical setting needs to be confirmed. When applying manual hyperinflation to enhance secretion movement, using the slowest inspiratory flow rate that the patient will tolerate is recommended.

It appears that, in current practice, physiotherapists do use rapid release to enhance secretion clearance, as the PEFR for the Choice Trial was similar to that of the Standardised Trials at an equivalent volume. Of interest is that physiotherapists may choose not to use rapid release in some situations. This is the first time this has been reported and exactly what physiotherapists do to produce a rapid release has yet to be described. Why rapid release influenced PIFR is not clear, however, and as the effect was very small it probably is clinically insignificant.

Figure 4. PEFR and I:E flow rate ratio for the two release techniques in the Standardised Trials, mean (SEM) for all subjects. A: PEFR. B: I:E flow rate ratio. The dashed line in panel B represents an I:E ratio of 0.9. * = $p < 0.05$ comparing slow to rapid release, # = $p < 0.05$ comparing Mapleson circuits at 1.4 litres to the Air Viva 2. • = $p < 0.05$ comparing the two target volumes for the Mapleson circuits, ns = not significant. (AV = Air Viva 2, MC = Mapleson-C, MF = Mapleson-F, 1.4 = 1.4 litres, E = empty the bag, PIFR = peak inspiratory flow rate, PEFR = peak expiratory flow rate, I:E = inspiratory to expiratory flow rate ratio).
Circuit type, volume delivered and operator performance did influence flow rates during manual hyperinflation. By controlling inspiratory time and volume delivered, PIFR for the Standardised Trials should have been similar at the same target volumes. Peak inspiratory flow rate was faster for the Air Viva 2 than for the Mapleson circuits and this suggests that the circuit type had an effect on inspiratory flow rate. The silicon reservoir bag of the Air Viva 2 is less compliant than the black re-breathing bag of the Mapleson circuits and, when the silicon bag is compressed, areas not directly in contact with the operator’s hand tend to compress. In comparison, only the area of the black re-breathing bag being directly compressed contributes to the volume being delivered, thus a smaller volume is delivered for the same area and force of hand compression, which may account for the lower PIFR. For the Standardised Trials, PEFR was significantly slower for the Air Viva 2 and rapid release did not produce as large an increase in PEFR compared with the Mapleson circuits. These findings would indicate that the Air Viva 2 circuit limits PEFR.

The use of rapid release at the target volume of 1.4 litres produced an I:E ratio of less than 0.9. As a consequence of the faster PIFR and slower PEFR, the I:E ratio for the Air Viva 2 was greater than that of the Mapleson circuits. At the larger target volume, the PEFR was faster but the I:E ratio was higher than that for the 1.4 L target trials because of the faster PIFR. These differences in I:E ratio may be clinically significant. Benjamin et al (1989) have shown in an intubated sheep model that the lower the I:E ratio during mechanical ventilation, the greater the clearance of a mucus simulant placed in the sheep’s trachea. Based on the findings of those studies, the Mapleson-C or the Mapleson-F circuits may be more appropriate for enhancing secretion clearance.

The PEFR for all Standardised Trials in this study were faster than the expiratory flow rates shown by Kim et al (1985) to promote movement of viscoelastic mucus simulants in a tube model. In their study, expiratory flow rates of between 0.5 and 1.0 L/sec, with an I:E ratio between 0.33 and 0.67, moved secretions in the direction of expiration (upwards) in a vertical tube with an internal diameter of 1.0 cm (representing a human trachea or main bronchi). The study by Kim et al (1985) and that of Benjamin et al (1989) both reported that, provided the critical expiratory flow was reached, the lower the I:E ratio the greater the movement of the simulant in an expiratory direction. If a lower I:E ratio is more effective in moving secretions, then performing manual hyperinflation with rapid release at the lower target volume would be the recommended technique as the risk of volutrauma or barotrauma would be minimised.

Conclusion

This study has confirmed that physiotherapists in the State of New South Wales use a variety of resuscitation circuits when performing manual hyperinflation. Physiotherapists do appear to use rapid release in current practice, however it seems that performance of the inspiratory phase varies from the original description in that despite therapists claiming to perform a slow inspiration, inspiratory time is less than three seconds. The implication of this in the clinical setting is that the I:E ratio may not meet theoretical requirements to enhance secretion movement. If, however, attention is directed towards a slow inspiration (three seconds), this requirement can be met. Further research is required to see if this can be reproduced in the clinical setting.

Circuit type and operator performance (the use of rapid release) can influence both inspiratory and expiratory flow rates and therefore the I:E ratio. Rapid release does increase expiratory flow rate irrespective of circuit type. The use of rapid release is recommended to enhance secretion clearance however, the effect of this in the clinical setting needs to be confirmed. How to perform rapid release needs to be described.

The Mapleson-F and Mapleson-C circuits produce lower I:E ratio than the Air Viva 2 at the target volume of 1.4 litres and therefore are recommended when performing manual hyperinflation for secretion clearance if available. The additional volume achieved when emptying the bag of the Mapleson circuits, although producing a faster PEFR, does not reduce the I:E ratio, as PIFR is also increased. Theoretically increasing inspiratory time would reduce PIFR but in practice, patient tolerance to a prolonged inspiratory time may limit this.

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References


