Comparison of three manual ventilation devices using an intubated mannequin

S G Hussey, C A Ryan, B P Murphy

Objective: To compare three devices for manual neonatal ventilation.
Design: Participants performed a two minute period of ventilation using a self inflating device, an anaesthesia bag with attached manometer, and a Neopuff device. An intubated neonatal mannequin, approximating a 1 kg infant with functional lungs, was used for the study. Target ventilation variables included a rate of 40 breaths per minute, peak inspiratory pressure (PIP) of 20 cm H₂O, and positive end expiratory pressure (PEEP) of 4 cm H₂O. The circuit was attached to a laptop computer for data recording.

Results: Thirty five participants were enrolled, including consultant neonatologists, paediatricians, and anaesthetists, paediatric and anaesthetic registrars, and neonatal nurses. The maximum PIP recorded using the self inflating bag, anaesthetic bag, and Neopuff device were 75.9, 35.5, and 22.4 cm H₂O respectively. There were significant differences between the devices for mean PIP (30.7, 18.1, and 20.1 cm H₂O), mean PEEP (0.2, 2.8, and 4.4 cm H₂O), mean airway pressure (7.6, 8.5, and 10.9 cm H₂O), % total breaths < 21 cm H₂O PIP (39%, 92%, and 98%), and % total breaths >= 30 cm H₂O PIP (45%, 0, and 0). There was no difference between doctors and allied health professionals for the variables examined.

Conclusion: The anaesthetic bag with manometer and Neopuff device both facilitate accurate and reproducible manual ventilation. Self inflating devices without modifications are not as consistent by comparison and should incorporate a manometer and a PEEP device, particularly when used for resuscitation of very low birthweight infants.

METHODS
Participants were recruited at in-service training days. They included 10 neonatal nurses, 11 consultant paediatricians and anaesthetists, 11 junior and middle grade paediatricians and anaesthetists, an emergency medical technician, a public health physician, and a midwife. A specially developed neonatal mannequin (approximating a 1 kg infant) with an endotracheal tube, functional lungs, and incorporated pressure transducer was used for this study (Fisher & Paykel). Air flow of 5 litres/min was delivered using a portable air compressor. The circuit was connected to an analogue to digital converter. Pressure waves were recorded continuously for each two minute study period on a dedicated laptop computer (Toshiba, USA). Information compiled for each participant included maximum PIP, mean PIP, mean airway pressure, mean PEEP, and ventilation rate.

Three devices were compared: an infant size, silicone, self inflating bag (Laerdal Medical, Stavanger, Norway); a disposable, flow dependent, latex free anaesthesia bag attached to a manometer (Intersurgical, Wokingham, UK); and a Neopuff device. The self inflating bag had a pop off valve set to activate at PIPs in excess of 40 cm H₂O. The anaesthetic bag circuit did not incorporate a flow control valve. The operator could control the volume and pressure of the bag by adjusting the egress at the open end of the bag with their thumb and forefinger. The Neopuff settings were preset by each participant before testing. Participants were asked to provide positive pressure ventilation for a period of two minutes with each of the three devices, aiming to achieve 40 breaths per minute, delivering a PIP and PEEP of 20 cm H₂O and 4 cm H₂O respectively. Each operator was able to observe chest movements during ventilation in addition to a

Abbreviations: PEEP, positive end expiratory pressure; PIP, peak inspiratory pressure

The reported need for positive pressure ventilation in newborn infants has varied from about 2% in the 1970s to 1% in the early 1990s. Infants receiving ventilatory support often require brief periods of manual ventilation for reasons including acute deterioration, equipment failure, patient transfer, and clinical assessment. Loss of face mask seal and loss of pressure in the ventilation bag can lead to inadequate resuscitation. Although ventilation is essential for resuscitation, excessive inspiratory pressures can lead to volutrauma, particularly in very low birthweight infants. Inadequate positive end expiratory pressure (PEEP) and the resultant inadequate end expiratory lung volume augments lung injury by allowing repetitive expansion and collapse of the terminal airways and alveolar units (atelectrauma). There are several methods of providing manual ventilation. Self inflating devices are operated by squeezing and releasing a semirigid silicone bag to deliver each breath to the patient. They are portable and easy to use. They usually include a pressure limiting safety valve and can deliver room air without an independent gas flow. Flow dependent anaesthesia bags are squeezed to deliver each breath, and pressure release valves can be attached to limit peak pressures. Their accurate use requires training and skill but they can facilitate both prolonged inspirations and PEEP. The Neopuff (Fisher & Paykel, Auckland, New Zealand) is a flow controlled, pressure limited mechanical device specifically designed for neonatal resuscitation. Breaths are delivered by occluding a T piece. Peak inspiratory pressure (PIP) is preset, and PEEP can be adjusted using the twist valve at the top of the T piece.

The aim of our study was to compare the effectiveness of and consistency in manual ventilation by trained healthcare professionals using three devices: a self inflating bag, a disposable flow dependent anaesthesia bag with attached manometer, and a Neopuff device.
manometer while using either the anaesthesia bag or the Neopuff. A timer clock was not visible to participants. Candidates were not allowed to view their continuous recordings and were only shown a graphic representation of their performance at the end of the entire assessment.

The data were analysed with analysis of variance and one sample $t$-testing using SPSS version 11 for Windows. Data were reported as mean (SEM). For each measured response, a repeated measures analysis of variance was conducted to investigate the effects of device type (self inflating bag, anaesthetic bag, Neopuff), operator (medical, non-medical), and the interaction between these two factors. One sample $t$-tests were performed to investigate if the target PIP, PEEP, and ventilation rates were achieved. Post hoc testing was performed using the Bonferroni test.

RESULTS
Thirty five healthcare workers participated in the study. There were insufficient participants to allow accurate statistical comparison between either individuals or subspecialists. Candidates were therefore designated as either doctors (n = 23) or allied health professionals (n = 12) (tables 1 and 2 respectively). There were no significant differences between the doctors and the allied health professionals (p > 0.05) for all variables examined. The maximum PIP values recorded using the self inflating bag, anaesthetic bag, and Neopuff device were 75.9 cm H$_2$O, 35.5 cm H$_2$O, and 22.4 cm H$_2$O respectively. The median value for mean maximum PIP was 46.3 cm H$_2$O, 22.0 cm H$_2$O, and 20.2 cm H$_2$O for the self inflating, anaesthetic, and Neopuff devices. Significant differences were found between the three devices for several variables (table 3).

The self inflating bag produced greater mean and maximum PIP and negligible PEEP values than the anaesthetic bag and Neopuff. Mean PEEP values for the anaesthetic bag were significantly lower than for Neopuff. Mean airway pressure was significantly greater using Neopuff compared with the anaesthetic and self inflating bags.

The recordings of each participant were further analysed to determine how many breaths remained within our target parameter of 20 cm H$_2$O PIP; 61% of breaths with the self

<table>
<thead>
<tr>
<th>Subject</th>
<th>Max PIP</th>
<th>Mean PIP</th>
<th>Mean PEEP</th>
<th>Max PIP</th>
<th>Mean PIP</th>
<th>Mean PEEP</th>
<th>Max PIP</th>
<th>Mean PIP</th>
<th>Mean PEEP</th>
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<tbody>
<tr>
<td>NeoNur 1</td>
<td>47.1</td>
<td>41.6</td>
<td>0.1</td>
<td>22.8</td>
<td>19.8</td>
<td>2.5</td>
<td>20.7</td>
<td>20.5</td>
<td>4.2</td>
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<tr>
<td>NeoNur 2</td>
<td>39.9</td>
<td>36.5</td>
<td>0.0</td>
<td>23.1</td>
<td>18.8</td>
<td>2.2</td>
<td>20.4</td>
<td>20.3</td>
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<td>NeoNur 3</td>
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<td>31.4</td>
<td>0.0</td>
<td>20.9</td>
<td>17.3</td>
<td>2.3</td>
<td>20.5</td>
<td>19.9</td>
<td>3.5</td>
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<tr>
<td>NeoNur 4</td>
<td>54.5</td>
<td>40.2</td>
<td>0.0</td>
<td>22.1</td>
<td>18.2</td>
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<td>20.4</td>
<td>4.1</td>
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<td>NeoNur 5</td>
<td>50.3</td>
<td>30.1</td>
<td>0.2</td>
<td>18.7</td>
<td>16.8</td>
<td>3.8</td>
<td>20.1</td>
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<td>3.9</td>
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<td>NeoNur 6</td>
<td>36.9</td>
<td>24.4</td>
<td>0.1</td>
<td>16.8</td>
<td>12.9</td>
<td>1.5</td>
<td>19.8</td>
<td>19.4</td>
<td>4.2</td>
</tr>
<tr>
<td>NeoNur 7</td>
<td>28.3</td>
<td>18.6</td>
<td>0.1</td>
<td>21.3</td>
<td>18.1</td>
<td>4.0</td>
<td>19.8</td>
<td>19.6</td>
<td>3.8</td>
</tr>
<tr>
<td>NeoNur 8</td>
<td>27.6</td>
<td>18.8</td>
<td>0.1</td>
<td>19.8</td>
<td>17.1</td>
<td>1.9</td>
<td>19.9</td>
<td>19.5</td>
<td>5.1</td>
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<tr>
<td>NeoNur 9</td>
<td>47.0</td>
<td>13.8</td>
<td>0.1</td>
<td>20.2</td>
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<td>2.4</td>
<td>20.1</td>
<td>19.9</td>
<td>4.6</td>
</tr>
<tr>
<td>NeoNur 10</td>
<td>39.4</td>
<td>21.9</td>
<td>0.1</td>
<td>24.7</td>
<td>17.8</td>
<td>4.1</td>
<td>20.3</td>
<td>20.1</td>
<td>4.7</td>
</tr>
<tr>
<td>MW1</td>
<td>61.7</td>
<td>41.9</td>
<td>0.1</td>
<td>27.5</td>
<td>20.8</td>
<td>2.4</td>
<td>20.6</td>
<td>20.4</td>
<td>4.7</td>
</tr>
<tr>
<td>EMT 1</td>
<td>25.5</td>
<td>21.6</td>
<td>0.1</td>
<td>13.9</td>
<td>10.8</td>
<td>0.7</td>
<td>20.1</td>
<td>20.1</td>
<td>5.2</td>
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</tbody>
</table>

Values were recorded in cm H$_2$O.

NeoNur, Neonatal nurse; MW, midwife; EMT, emergency medical technician.
inflating bag exceeded 21 cm H\(_2\)O and 45% exceeded 30 cm H\(_2\)O, which was significantly different from the anaesthetic bag and Neopuff.

The one sample t tests performed for each device showed significant deviations from the set target parameters of PIP and PEEP for both the self inflating and anaesthetic bag devices (p < 0.001) and also for target rate (p < 0.05). The Neopuff device was more consistent and reliable in its performance by comparison.

**DISCUSSION**

Recent studies have highlighted the diversity of resuscitation equipment in routine use at maternity hospitals. A UK survey showed the T piece device to be the most popular device for resuscitation, with just 12% of maternity units using a self inflating bag.10 O’Donnell et al,11 in contrast, report the self inflating bag as the device of choice for most resuscitations in 17 of 29 tertiary hospitals in Australia and New Zealand.

The ability to perform consistent manual ventilation has been shown in this study to be equipment dependent and independent of professional grouping. The Neopuff and anaesthesia bags were comparable in terms of delivery of appropriate PIP and PEEP. Although there was a significant statistical difference between the Neopuff device and anaesthesia bag relating to mean and maximum PIP and mean PEEP, these differences are probably negligible in clinical practice. Self inflating devices without a manometer and possibly a PEEP valve should not be considered as first choice for manual ventilation of very low birthweight infants as they facilitate excessively high PIP and minimal PEEP.

This is the first study, to our knowledge, that compares all three resuscitation devices using an intubated model. Inaccurate face mask application resulting in air leakage is a major reason for failure of infants to respond to bag and mask ventilation at resuscitation.7 In this study, we used an intubated mannequin to minimise leak complications when using the various devices. Finer et al13 compared the resuscitation performance of 27 healthcare professionals using the Neopuff device, a disposable anaesthesia bag, and Jackson-Rees anaesthesia bag with attached manometers. That study used bag and mask ventilation rather than endotracheal tube ventilation and concluded that Neopuff was superior to both anaesthesia bags. Respiratory therapists were consistently better at delivering PIP and PEEP than the other professional groups studied. Neonatal resuscitation in Ireland and Europe principally involves trained doctors and nurses. Our study did not show any difference between these professional groups, but did show differences between all three devices for several variables.

Appropriate use of an anaesthetic bag is dependent on adequate training and practice with the device, otherwise its advantages are redundant and the device itself potentially dangerous. Mondolfo et al15 described more ventilation failures and less operator confidence when using the anaesthesia bag compared with the self inflating bag in a paediatric emergency department. Kanter16 also reported technical difficulties with anaesthesia bags resulting in underventilation coupled with a tendency to both overventilate and use excessive pressures with self inflating bags.17 Advocates of the anaesthesia bag often cite the ability to “feel” the changes in lung compliance as an advantage. However, this has not been shown to any reliable extent and is rooted more in anecdote than evidence.15 What has been shown to enhance ventilation performance with the anaesthesia bag is the attachment of a manometer, allowing more controlled ventilation in terms of peak pressures generated and overall mean airway pressure and thus oxygenation.18 19 Zmora and Merritt14 examined manual ventilation of a mannequin by paediatric staff both with and without a manometer. Target inspiratory pressures were achieved by 72% using a manometer in contrast with 18% without.

The appeal of the self inflating resuscitation bag lies in its simplicity of use such that even the most junior staff present can operate the device. However, from several perspectives the self inflating bag is not ideal. Kain et al20 described unrecordable tidal volumes for self inflating bags that would result in clinically significant hypoventilation during actual resuscitation. Different studies by Martel and Soder19 and Finer et al20 have highlighted the limitations of self inflating devices in terms of oxygen delivery. Although the use of 100% oxygen at resuscitation is now questioned by some, the current Neonatal Resuscitation Programme guidelines still recommend resuscitation with 100% oxygen.21–24 There is also growing evidence to support the use of prolonged initial ventilations at newborn resuscitation, which can easily be delivered with the Neopuff and anaesthesia bags.25 26 Self inflating devices may not facilitate as adequate a prolonged ventilation as these devices, although our study did not test the ability to provide prolonged individual ventilations with each device.

Anaesthesia bag circuits, by convention, have manometers attached for safety. Self inflating bags have pressure release safety valves set to activate at predetermined pressures. In designing this study, we considered using a manometer with the self inflating bag. Manometer attachment is optional on some self inflating bags but is not in widespread practice to be strongly considered for neonatal resuscitation, especially in very low birthweight infants.

The ability to provide a consistent predetermined rate of ventilation has been studied previously.27 Whyte et al described how none of 33 individual resuscitators were able to deliver 40 breaths per minute during a simulated resuscitation, whereas of 18 pairs of rescuers, four achieved 40 breaths per minute. Our results show that, overall, there was no significant deviation from the target rate of 40 per minute.

<table>
<thead>
<tr>
<th>Table 3 Ventilatory variables</th>
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<tbody>
<tr>
<td>Response</td>
</tr>
<tr>
<td>Mean max PIP</td>
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<tr>
<td>Mean PIP</td>
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<td>Mean PEEP</td>
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<tr>
<td>Mean airway pressure</td>
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<tr>
<td>Mean rate</td>
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<tr>
<td>% total breaths &lt; 21 cm H(_2)O PIP</td>
</tr>
<tr>
<td>% total breaths &gt; 30 cm H(_2)O PIP</td>
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</tbody>
</table>

Values are mean (SEM). Values followed by an asterisk within the same row are not significantly different (p > 0.05). PEEP, Positive end expiratory pressure; PIP, peak inspiratory pressure.
minute while using the Neopuff device, unlike the other two
devices studied.

When designing this study we used an air compressor to
generate flow of 5 litres/min, in keeping with Neonatal
Resuscitation Programme guidelines. A PEEP of 4 cm H$_2$O
was possible at this flow setting with both the anaesthetic
bag and the Neopuff device. Add on PEEP apparatus for self
inflating bags are available but are currently not widely used.
O'Donnell et al$^{12}$ reported that only two of 29 tertiary neonatal
units used PEEP devices on self inflating bags. In order to
reflect clinical practice on the ground, we did not use a PEEP
valve adaptation on the self inflating bag in this study.

CONCLUSION
The anaesthetic bag with manometer and Neopuff device
both facilitate accurate and reproducible manual ventilation
by healthcare professionals, irrespective of professional
background. Neonatal resuscitation training programmes
should incorporate the Neopuff (or a similar device) or the
anesthesia bag with attached manometer to provide PEEP
and controlled PIP. Units using self inflating devices should
attach at least a manometer and possibly a PEEP valve
mechanism for newborn resuscitation, particularly for very
low birthweight infants.

ACKNOWLEDGEMENTS
We thank Kathleen O’Sullivan for her invaluable help with the
statistical analysis.

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Fisher & Paykel supplied the Neopuff device, mannequin, and recording
software for this study. The authors have neither financial interests nor
other relationships with the companies whose products or services are
discussed.

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Arch Dis Child Fetal Neonatal Ed 2004 89: F490-F493
doi: 10.1136/adc.2003.047712

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