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Simulation and education

Manual ventilation devices in neonatal resuscitation: Tidal volume and positive pressure-provision☆

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ABSTRACT

Background: Excessive peak inspiratory pressures (PIP) and high tidal volumes (Vt) during manual ventilation can be detrimental to the neonatal lung. We compared the influence of different manual ventilation devices and individual professional experience on the extent of applied Vt and PIP in simulated neonatal resuscitation.
Material and methods: One hundred and twenty medical professionals were studied. An intubated mannequin (equivalent to 1.0 kg neonate) was ventilated using two different devices: a self-inflating bag and a T-piece resuscitator. Target value was a PIP of 20 cm H_2O. Applied PIP and the resulting Vt were recorded continuously using a respiratory function monitor (CO_2SMO^+, Novametrix, USA).
Results: Vt and PIP provision was significantly higher in SI-bags, compared to T-piece devices: median (interquartile range) PIP 25.6 (18.2) cm H_2O vs 19.7 (3.2) cm H_2O ($p < 0.0005$), and Vt 5.1(3.2) ml vs Vt 3.6 (0.8) ml ($p < 0.0005$) respectively. The intersubject variability of Vt and PIP provision was distinctly higher in SI-bags, compared to T-piece devices. Professional experience had no significant impact on the level and the variability of Vt or PIP provided.
Conclusion: Use of T-piece devices guarantees reliable and constant Vt and PIP provision, irrespective of individual, operator dependent variables. Methods to measure and to avoid excessive tidal volumes in neonatal resuscitation need to be developed.

1. Introduction

Non-invasive respiratory support of the depressed newborn after birth is among the most frequently performed and pertinent manoeuvres in neonatal medicine, particularly in very low birth weight infants (VLBW).[1] Earlier work by Dreyfuss and Saumon showed the harmful impact of a high volume stretch on the neonatal lung, caused by excessive peak inspiratory pressure (PIP) and high positive end expiratory pressure (PEEP).[2] Due to the immaturity of the lung and thorax, VLBW infants are particularly vulnerable to baro- and volutrauma and consequently chronic lung disease.[3] These insults to the respiratory system are often inflicted as early as during the initial management in the delivery room.[4,5] However, routine monitoring of applied pressures (PIP or PEEP) and in particular tidal volumes (Vt) is not common practice in most delivery rooms (DR).[6,7]

The most commonly used devices for providing manual respiratory support are self-inflating bags (SI-bags). According to international surveys, these are being used in 83–92% of delivery units world wide.[6–9] SI-bags are mostly used without pressure manometers or appropriate pressure control.[7] Pressure limited devices, usually referred to as T-piece devices, have been commercially available for a number of years now. According to the above named surveys, near to 40% of units world wide now use such devices.[7–9] The recent ILCOR and ERC guidelines equally recognize the SI-Bag and the T-piece device for neonatal resuscitation.[10,11]

T-piece devices were shown to be superior over SI-bags in delivering pressure controlled PIP and PEEP during manual ventilation.[12–15] However, in adaption to the work by Hillman et al., we believe that in order to reduce neonatal lung injury not only PIP and PEEP need to be considered, but also the provision of high tidal volumes has to be avoided during neonatal resuscitation.[16]

Using a mannequin, we sought to compare the two most commonly used manual ventilation devices in terms of Vt and PIP

Abbreviations: DR, delivery room; ERC, European Resuscitation Council; ILCOR, International Liaison Committee on Resuscitation; IQR, interquartile range; MV, manual ventilation; NR, neonatal resuscitation; PEEP, positive end expiratory pressure; PIP, peak inspiratory pressure; PPV, positive pressure ventilation; RR, respiratory rate; SI-bag, self-inflating bag; T-piece device, T-piece ventilation device or resuscitator; Ti, inspiratory time; VLBW, very low birth weight; Vt, tidal volume.

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provision in a large operator-collective matching the scenario of daily delivery room routine. We hypothesized that the provision of Vt and PIP depends both on the equipment and individual, operator dependent variables.

2. Materials and methods

2.1. Study population and design

In a prospective randomized cross-over design we investigated the individual performance of health care professionals from different fields of medicine involved in neonatal resuscitation. A total of 120 individuals were recruited at workshops held on neonatal resuscitation and stratified to their profession: 20 Paediatricians, 22 Obstetricians, 23 Anaesthesiologists, 30 Neonatal Nurses and 25 Midwives. In a standardized interview information was obtained regarding the number of neonatal resuscitations attended per year and exposure to formal resuscitation training.

2.1.1. Set up

We simulated neonatal resuscitation using a neonatal mannequin resembling a VLBW infant, approximating a 1 kg infants lung with a compliance of 0.2 ml kPa^{-1} (Fisher & Paykel Healthcare, Auckland, NZ). The model was leak free, intubated and either the resuscitation bag or the T-piece device could be fitted on to the mannequin's endotracheal tube. A continuous gas flow of 8l/min was delivered using wall mounted medical air. A pneumotachograph ($CO_2SMO^{+®}$, Novametrix Inc., Wellingford, CT, USA) was fitted at the interface between mannequin and resuscitation device to measure airflow, applied volume and pressure. These signals were recorded on a laptop computer.

2.1.2. Resuscitation devices

Two different manual ventilation devices were used: a new 240 ml Laerdal®-bag (Laerdal, Oslo, Norway) with a new Ambu®-10-PEEP-valve (Ambu, Denmark) set at 5 cm H_2O and a T-piece device (Neopuff®, Fisher & Paykel, Auckland, New Zealand) with the PEEP set at 5 cm H_2O. The T-piece device settings (PIP and PEEP) were set anew by each participant at the start of the experiment. In order to ensure that all tested individuals had an equal understanding of the use of both devices, we gave a brief tutorial on the theoretical background and means of operation of both devices prior to testing. The tutorial included reference to the expected respiratory rate, peak pressures and tidal volumes when managing a 1 kg neonate.

2.1.3. Scenario

The participants were given the scenario of an apnoeic newborn VLBW neonate in the DR, which had been already intubated and given surfactant by the team. Each participant was asked to manually ventilate at a PIP of 20 cm H_2O and a PEEP of 5 cm H_2O with a rate of approximately 60 breaths/min. The models chest excursions were visible throughout the experiment.

Data recording was blinded to the operator. The participants were separately investigated in random order with either an SI-bag or a T-piece device as the first device and changed to the second device thereafter. The order was reversed for every other participant. Manual ventilation for each device was recorded over a period of 3 min per participant (90 s for each device).

2.2. Statistical analysis

All data was tested for normality with a Kolmogorov–Smirnov-Test. Measured pressures and volumes are presented as median (interquartile range, IQR) unless otherwise stated. Non-parametric-tests were used for comparison of 2 (Mann–Whitney test) and more than 2 groups (Kruskal–Wallis-test). SPSS version 16.0 was used for statistical analysis (SPSS Inc., Chicago, IL, USA). A p-value <0.05 was considered significant.

Table 1
Participant's characteristics (number of analyzed cycles in parenthesis).

	SI-bag, $n = 120$ (12,398)	T-piece device, $n = 120$ (10,902)
Professional group		
Obstetricians	22 (1877)	22 (1767)
Midwifes	25 (2612)	25 (2340)
Paediatricians	20 (1988)	20 (1808)
Neonatal nurses	30 (3445)	30 (2645)
Anaesthesiologists	23 (2476)	23 (2342)
Number of neonatal resuscitations (per year)		
None	60 (5868)	60 (5600)
Up to 2 per year	26 (2849)	26 (2356)
>2 per year	34 (3681)	34 (2946)

3. Results

In total 120 professionals were tested and 23,300 respiratory cycles were analyzed. The participant's characteristics are shown in Table 1.

The median Vt (inter quartile range, IQR) for the SI-bag of 5.1 (3.2) ml was significantly higher ($p < 0.0005$) compared to the T-piece device of 3.6 (0.8) ml. The lowest recorded Vt in the SI-bag group was 1 ml, the max. Vt was 14.6 ml. In the T-piece device, minimal Vt was 1.3 ml and max. Vt was 5.7 ml (Fig. 1).

The median PIP (IQR) for the SI-bag was 25.6 (18.2) cm H_2O and significantly higher ($p < 0.001$) compared to T-piece device with 19.7 (0.6) cm H_2O (Fig. 2). The lowest recorded PIP for the SI-bag was 2.7 cm H_2O and the highest PIP was 59.8 cm H_2O. For the T-piece device, the minimum PIP was 10.5 cm H_2O and the max. 21.3 cm H_2O.

The median Ti for the SI-bag was 0.2 s compared to 0.4 s for the T-piece device ($p < 0.005$). The median respiratory rate for the SI-bag was 67/min and for the T-piece device 57.5/min ($p = 0.015$), respectively. We found no statistically significant difference in Vt or PIP provision between operators with frequent or infrequent exposure to neonatal resuscitation (Table 2) or between professional groups.

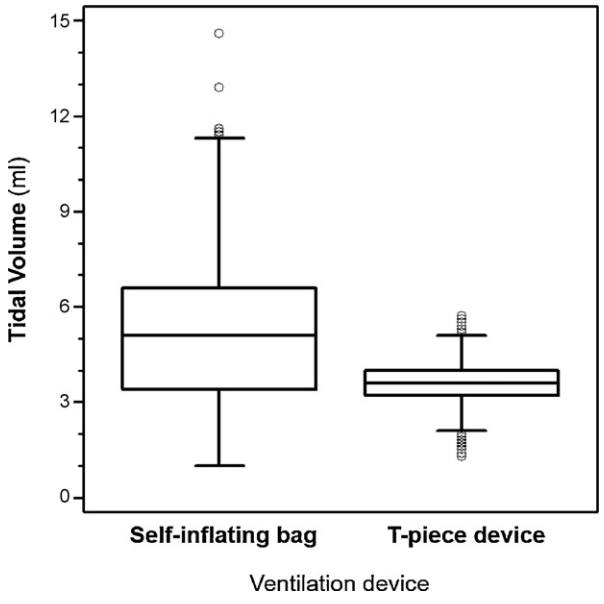

Fig. 1. Comparison of applied tidal volume (Vt) in ml between both ventilation devices used.

Table 2
Comparison of systems according to individual experience in NR.

Experience: NR per year	*n*	SI-bags			T-piece device		
		Median	$IQR_{25-75\%}$	*p*-Value	Median	$IQR_{25-75\%}$	*p*-Value
PIP (cm H_2O)							
0	60	28.6	20.6	0.275	19.8	0.5	0.187
1–2	26	22.9	16		19.7	0.5	
>2	34	19.3	19.3		19.7	0.8	
Vt (ml)							
0	60	5.3	3.9	0.239	3.7	0.8	0.859
1–2	26	4.8	3.1		3.6	0.8	
>2	34	4.1	3.4		3.6	0.6	

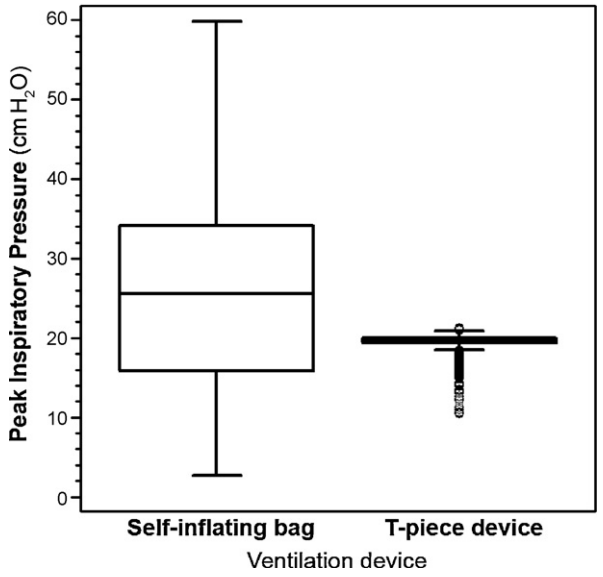

Fig. 2. Comparison of PIP between both ventilation devices used.

4. Discussion

We investigated the device specific effects on the provision of Vt and PIP in simulated neonatal resuscitation. To our knowledge, this is the first study to compare Vt-values administered by two commonly used manual ventilation devices in a leak free scenario. We found significant differences in provision of Vt and PIP between devices: the T-piece device did allow better control of both Vt and PIP provision. These observations are in keeping with those of other authors.[12–15] Concerning the operator dependent variations in PIP provision, our results are alike those of Hussey et al., who found no statistically significant difference in PIP provision by professional experience when comparing a group of medical professionals in using SI-bags, flow-inflating-bags or T-piece resuscitators.[13] Furthermore, our observations of heterogeneous levels of maximum PIPs delivered by SI-bag, irrespective of experience in neonatal resuscitation, are in keeping with Hussey et al. and Oddie et al.[13,17] Contrary to other authors, we found no significant difference when comparing professional groups. This was surprising and has prompted us to further investigate the relationship between professional exposure to resuscitation and professional training in resuscitation. Unlike as for instance in the USA, we did not include measurements with flow-inflating-bags (anaesthesia bags) in our investigation because we do not use these for resuscitation of premature infants in our unit.[18]

Excessive pressures will most likely be harmful to further lung development, whereas too little PIP will not be to the benefit of the patient either.[2] We have previously been able to show the wide variation in PEEP provision by SI-bags.[19] Similarly, the level of applied PIP by SI-bag showed large intra- and inter-operator variability. The range of applied PIP by SI-bag span from 0 to 58 cm H_2O, the use of such non-pressure limited devices, particularly in the hand of the untrained healthcare professional is potentially extremely dangerous. To the contrary, the use of a T-piece resuscitator led to PIP values ranging from 10 to 23 cm H_2O, hence over- or under-inflation were better controlled for PIP values of less than 15 cm H_2O occurred with the T-piece in less than 0.3% (30/10,902) of the analyzed ventilation curves. Some further findings of our study do warrant comment: we used a Laerdal SI-bag, which had a pop-off valve, set to open up at a PIP value of 35 cm H_2O. However, peak pressures observed during our experiment often exceeded 35 cm H_2O, despite seemingly proper functioning of the pop-off valve. We believe this is another point in favour of using pressure controlled T-piece devices as first line tools for providing manual respiratory support in neonatal resuscitation, particularly when considering a gentle ventilation strategy in order to avoid excessive neonatal volu- and barotrauma.

Our study has several limitations. First, we worked with a neonatal mannequin in a laboratory setting. It will then be a matter of further study to investigate whether our results can be directly applied to the clinical setting. The artificial lungs and mannequin were carefully designed to simulate a living baby, however they came without simulation of the dynamic changes in lung compliance that can be observed once the neonatal lung is opened and functional residual capacity has been established. However, it remains to be studied whether such subjectively felt changes in lung compliance do actually influence the operators' ventilation performance. Secondly, the model used was free of leak. To have a leak free model is important when measuring respiratory parameters, which are easily affected by small changes in gas volume. Other groups have recently looked into the extent of leak in neonatal ventilation.[20,21] Wood et al. have shown that irrespective of operator experience leak around face masks was above 50% under conditions of simulated manual ventilation.[21] However, the aim of our study was not to investigate airway leak size. A leak of such magnitude would have made most of our recordings impossible to analyze. For the purpose of our research, we therefore chose to investigate the device specific characteristics in a leak free and intubated model. Other studies in this field have used similar scenarios, however clinical studies are still being awaited.[12–15,22]

To summarize our findings, the choice of device has the strongest influence on Vt and PIP provision over any other contributing factors during simulated NR. However, we believe that regardless of the device used, both pressure and tidal volume control should become instrumental in NR. Further research should focus on the implementation of Vt monitoring as a standard monitoring parameter in routine neonatal care.

Conflict of interest

None.

References

1. Davis PG, Morley CJ, Owen LS. Non-invasive respiratory support of preterm neonates with respiratory distress: continuous positive airway pressure and nasal intermittent positive pressure ventilation. Semin Fetal Neonatal Med 2009;14:14–20.
2. Dreyfuss D, Saumon G. Ventilator-induced lung injury: lessons from experimental studies. Am J Respir Crit Care Med 1998;157:294–323.
3. Jobe AH, Hillman N, Polglase G, Kramer BW, Kallapur S, Pillow J. Injury and inflammation from resuscitation of the preterm infant. Neonatology 2008;94:190–6.
4. Vento M, Cheung PY, Aguar M. The first golden minutes of the extremely-low-gestational-age neonate: a gentle approach. Neonatology 2008;95: 286–98.
5. O'Donnell CP, Davis PG, Morley CJ. Resuscitation of premature infants: what are we doing wrong and can we do better? Biol Neonate 2003;84:76–82.
6. O'Donnell CP, Davis PG, Morley CJ. Use of supplementary equipment for resuscitation of newborn infants at tertiary perinatal centres in Australia and New Zealand. Acta Paediatr 2005;94:1261–5.
7. Roehr CC, Schmalisch G, Khakban A, Proquitté H, Wauer RR. Use of continuous positive airway pressure (CPAP) in neonatal units—a survey of current preferences and practice in Germany. Eur J Med Res 2007;12:139–44.
8. O'Donnell CP, Davis PG, Morley CJ. Positive pressure ventilation at neonatal resuscitation: review of equipment and international survey of practice. Acta Paediatr 2004;93:583–8.
9. Iriondo M, Thió M, Burón E, Salguero E, Aguayo J, Vento M. A survey of neonatal resuscitation in Spain: gaps between guidelines and practice. Acta Paediatr 2009;98:786–91.
10. International Liaison Committee on Resuscitation 2005. International consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Part 7: neonatal resuscitation. Resuscitation 2005;67:293–303.
11. Biarent D, Bingham R, Richmond S, et al. European Resuscitation Council guidelines for resuscitation 2005. Section 6. Paediatric life support. Resuscitation 2005;67(Suppl. 1):S97–133.
12. Finer NN, Rich W, Craft A, Henderson C. Comparison of methods of bag and mask ventilation for neonatal resuscitation. Resuscitation 2001;49:299–305.
13. Hussey SG, Ryan CA, Murphy BP. Comparison of three manual ventilation devices using an intubated mannequin. Arch Dis Child Fetal Neonatal Ed 2004;89:F490–3.
14. O'Donnell CP, Davis PG, Lau R, Dargaville PA, Doyle LW, Morley CJ. Neonatal resuscitation 2: an evaluation of manual ventilation devices and face masks. Arch Dis Child Fetal Neonatal Ed 2005;90:F392–6.
15. Bennett S, Finer NN, Rich W, Vaucher Y. A comparison of three neonatal resuscitation devices. Resuscitation 2005;67:113–8.
16. Hillman NH, Moss TJ, Kallapur SG, et al. Brief, large tidal volume ventilation initiates lung injury and a systemic response in fetal sheep. Am J Respir Crit Care Med 2007;176:575–81.
17. Oddie S, Wyllie J, Scally A. Use of self-inflating bags for neonatal resuscitation. Resuscitation 2005;67:109–12.
18. Leone TA, Rich W, Finer NN. A survey of delivery room resuscitation practices in the United States. Pediatrics 2006;117:e164–75.
19. Kelm M, Proquitté H, Schmalisch G, Roehr CC. Reliability of two common PEEP-generating devices used in neonatal resuscitation. Klin Padiatr 2009. Sep 3. [Epub ahead of print].
20. Mahmoud RA, Fischer HS, Proquitté H, Abudaif Shalaby HM, Schmalisch G. Relationship between endotracheal tube leakage and under-reading of tidal volume in neonatal ventilators. Acta Paediatr 2009;98:1116–22.
21. Wood FE, Morley CJ, Dawson JA, et al. Assessing the effectiveness of two neonatal face masks during simulated resuscitation: study 1. Arch Dis Child Fetal Neonatal Ed 2008;93:F235–7.
22. McHale S, Thomas M, Hayden E, Bergin K, McCallion N, Molloy EJ. Variation in inspiratory time and tidal volume with T-piece neonatal resuscitator: association with operator experience and distraction. Resuscitation 2008;79:230–3.