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Original Article

Peak pressure and tidal volume are affected by how the neonatal self-inflating bag is handled

Mariana A. Bassani,[1] Francisco Mezzacappa Filho,[2] Maria Regina C. Coppo,[3] Sérgio T. M. Marba[4]

Abstract

Objective: To evaluate how different ways of handling the neonatal self-inflating bag influence peak pressure and tidal volume.

Methods: This is an experimental study involving 141 different professionals (physicians, resident physicians, physiotherapists, nurses, and nursing technicians), who ventilated an artificial lung, adjusted to simulate the lung of a term neonate, using a self-inflating bag. Each professional handled the ventilator in five different ways: a) using both hands (10 fingers); and, with only one hand, b) five fingers, c) four fingers, d) three fingers, and e) two fingers. Peak pressure and tidal volume data were recorded by the artificial lung equipment.

Results: Both variables showed high variability, from 2.5 to 106.3 cmH_2O (mean = 39.73 cmH_2O; 95%CI 37.32-42.13) for peak pressure, and from to 4 to 88 mL (mean = 39.56 mL; 95%CI 36.86-42.25) for tidal volume. There was no significant influence of the profession on any of the variables ($p > 0.05$). However, bag handling significantly influenced both peak pressure and tidal volume ($p < 0.0001$), which were higher when the operator used both hands.

Conclusion: The results indicate that most professionals delivered excessively high peak pressures and tidal volumes, which could increase the risk of barotrauma and volutrauma, especially when both hands were used to ventilate. On the other hand, a small number of professionals delivered insufficient pressure and volume for adequate lung expansion and ventilation. The delivery of inadequate ventilation was not dependent on profession.

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Introduction

Manual lung ventilation using self-inflating bags is frequently performed by health professionals who provide neonatal intensive care. It is administered to promote oxygenation during anesthesia,[1] for ventilation during transport inside and outside the hospital setting,[2] as a respiratory physical therapy technique,[3] and particularly in cardiopulmonary resuscitation.[2,4-6] However, no consensus has been reached on its use. Although the advantages and disadvantages of using self-inflating bags have been well-reported in the literature, there are no recommendations on the use of such equipment, especially for resuscitation of newborns in the delivery room.[6,7]

1. Mestranda, Saúde da Criança e do Adolescente, Centro de Investigação em Pediatria (CIPED), Universidade Estadual de Campinas (UNICAMP), Campinas, SP, Brazil. Especialista, Fisioterapia em Neonatologia, Centro de Atenção Integral à Saúde da Mulher (CAISM), UNICAMP, Campinas, SP, Brazil. Fisioterapeuta, CAISM, UNICAMP, Campinas, SP, Brazil.
2. Médico neonatologista. Professor assistente, Departamento de Pediatria, CAISM, UNICAMP, Campinas, SP, Brazil.
3. Mestre, Saúde da Criança e do Adolescente, CIPED, UNICAMP, Campinas, SP, Brazil. Fisioterapeuta, CAISM, UNICAMP, Campinas, SP, Brazil.
4. Médico neonatologista, CAISM, UNICAMP, Campinas, SP, Brazil. Professor associado, Departamento de Pediatria, Faculdade de Ciências Médicas, UNICAMP, Campinas, SP, Brazil.

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Several studies have shown that the ventilatory parameters produced during manual lung ventilation can be highly influenced by many factors, such as profession[8,9] and professional experience,[8,10,11] equipment and circuits employed,[3,9,11-13] hand size,[14-16] and use of one or both hands.[8,15-18]

In addition, the use of self-inflating resuscitators poses high risk of lung injury, which may later cause chronic lung diseases in childhood.[5] The risk of barotrauma due to high peak airway pressure is not the only presentation of lung injury caused by the use of self-inflating bags.[5,19] The use of excessive tidal volumes causes alveolar and lung parenchyma distension, triggering inflammatory cascade, and, as a consequence, injury of the respiratory epithelium,[7,19,20] mainly in extreme preterm newborns, whose lungs are still undergoing development.[20] Another concern during manual lung ventilation is the supply of low volumes and pressures, which may be insufficient to promote appropriate ventilation in newborns.[21] Hypoventilation, which leads to hypoxemia, hypercapnia and acidosis, worsens the patient's clinical condition and prognosis.

Knowledge about the factors that may affect the ventilatory parameters produced during manual lung ventilation with self-inflating bags is extremely important, since it can contribute to technique standardization and, thus, to a safer and more efficient performance, reducing complications and providing patients with better prognosis and shorter hospital stay, and resulting in lower hospital costs.

The objective of the present study was to analyze how the handling of the neonatal manual lung ventilator with a self-inflating bag by different health professionals influences peak pressure and tidal volume.

Methods

This is an experimental study involving health professionals (physicians, resident physicians, physical therapists, nurses and nursing technicians) who work at the neonatal intensive care unit (NICU) of the Center of Integral Attention to Women's Health (Centro de Atenção Integral à Saúde da Mulher – CAISM) of Universidade Estadual de Campinas (UNICAMP), state of São Paulo, Brazil. After reading and signing the written consent form, volunteers operated a new self-inflating manual lung ventilator, neonatal model, equipped with a silicon bag with maximum capacity of 300 mL (J. G. Moriya®) to ventilate an artificial lung (Adult/Infant Ventilator Tester, mod. VT-2, Bio-Tek, Winooski, VT) calibrated and adjusted with airway resistance (200 $cmH_2O/L/min$) and lung compliance (0.003 L/cmH_2O) compatible with physiological values of an intubated term newborn (approximately 3 kg). This manual lung ventilator was selected for this study because it is the model most often used at the NICU in our hospital. For this study, there were not reservoir and source of compressed gas connected to the bag. The relief valve, of which activation pressure is equal to or higher than 40 cmH_2O (according to the manufacturer), remained unlocked. The artificial lung used in this study simulates the human lung through adjustment of compliance (provided by a spring system) and resistance (provided by resistors of different diameters) as desired. Flow and pressure transducers, located inside the equipment, convert the information in electrical signal, which is processed and displayed on a liquid crystal screen and/or printed by a built-in printer. This device is in compliance with the norms of the American Society for Testing and Materials F920-93. All tests were performed using the equipment adjusted for barometric pressure of 760 mmHg, at 25 ºC of room temperature and 50% of relative air humidity.

Five different ways of handling the manual lung ventilator were tested (method similar to that employed by Ganga-Zandzou et al.[22]): a) using both hands (10 fingers); and using one hand: b) five fingers; c) four fingers; d) three fingers; e) two fingers.

The delivered values of peak pressure and tidal volume were computed and recorded by the artificial lung after approximately five cycles provided by each volunteer. An interval of approximately 1 minute was allowed between maneuvers with different ways of handling. The sequence of five ways of handling was previously defined based on a random number table,[23] and the volunteers were blind to the results during data collection.

This study protocol was approved by the Committee for Ethics in Research of the School of Medicine of UNICAMP.

The statistical analysis was carried out using the software GraphPad Prism version 4.0 (2003). The Kolmogorov-Smirnov test was used to assess the normality of the sample. The influence of different ways of handling on peak pressure, which had normal distribution, was tested by means of one-way analysis of variance for paired samples, followed by post hoc Bonferroni's test. To analyze the tidal volume, which did not show normal distribution, we used the non-parametric Friedman's test and post hoc Dunn's test. In order to investigate the influence of health professionals' training on these variables, we used one-way analysis of variance for independent samples (parametric), since normal distribution of data was achieved. For the latter analysis, we considered the values provided by each professional group with the five fingers handling, which is most often used in neonatology. Significance level was set at $p < 0.05$.

Results

One hundred and forty-one health professionals who worked at the NICU of CAISM/UNICAMP were included, of which 29 were nurses, 11 were assistant physicians or professors, 20 were resident physicians, 49 were nursing technicians, and 32 were physical therapists. We did not find statistically significant influence of profession on the values provided for peak pressure ($p = 0.659$) and tidal volume ($p = 0.206$) (Table 1).

We found that the way of handling the manual lung ventilator had a significant influence ($p < 0.0001$) on peak pressure and tidal volume when the ventilator was handled with both hands when compared to the use of only one hand. The post hoc test peak pressure values generated using 10 fingers were significantly higher than those resulting from the use of five, four, three ($p < 0.01$) and two ($p < 0.001$) fingers. For tidal volume, we found a significant difference between 10 and four, three and two fingers ($p < 0.01$).

Table 2 shows the means, standard deviation, 95% confidence interval (95%CI), and minimum and maximum values for peak pressure and median, interquartile range, 95%CI, and minimum and maximum values for tidal volume for each different handling, as well as the results of the statistical analyses performed.

It is important to stress that, regardless of the handling maneuver, we could observe a high variability for both variables. Considering all values of peak pressure and tidal volume produced with all different ways of handling by all professionals, the mean peak pressure was 39.73 cmH_2O (95%CI 37.32-42.13) ranging from 2.5 to 106.3 cmH_2O, and the mean value for tidal volume was 39.56 mL (95%CI 36.86-42.25) ranging from 4 to 88 mL.

Discussion

Currently, there are few studies on manual lung ventilation focused on equipment handling and professional influences, particularly with application to neonatology. We found only one study, by Ganga-Zandzou et al.,[22] which approached these factors with regard to ventilation of newborn patients. The authors studied the influence of different ways of handling on respiratory frequency, inspiratory time, tidal volume and peak pressure during manual lung ventilation of a newborn model. Four different ways of handling were analyzed (using five, four, three and two fingers), and the authors found that handling did not influence respiratory frequency, inspiratory time and tidal volume. There was influence of handling only on peak pressure, which was significantly higher with five than with two fingers (38.2±6.0 vs. 35.5±6.0, respectively; $p < 0.05$). There was partial agreement between these results and those found in the present study, which shows that handling significantly affected not only peak pressure, but also tidal volume. It is important to mention that in the present study, a significant difference was observed in the comparison between the use of one and both hands, but not among different ways of handling using only one hand. It is possible that the disagreement between these two studies regarding tidal volume is not due only to the different ways of handling, but also to the size of the sample, which comprised 141 and 19 individuals in the present report and in the study by Ganga-Zandzou et al.,[22] respectively. However, both studies found that the pressure values tend to be higher the greater the number of fingers used.

Table 1 - Influence of profession on the variables peak pressure and tidal volume

Variables	Mean ± SD	95%CI	Minimum	Maximum	p
Peak pressure (cmH_2O)					0.672*
Nurse (n = 29)	40.30±15.11	34.55-46.05	6.50	69.80	
Physician (n = 11)	39.78±10.26	32.89-46.67	19.70	51.30	
Resident physician (n = 20)	35.29±10.30	30.47-40.11	18.90	53.30	
Physical therapist (n = 32)	41.36±17.20	35.16-47.56	8.500	89.20	
Nursing technician (n = 49)	40.11±14.47	32.89-46.67	9.200	73.30	
Tidal volume (mL)					0.212*
Nurse (n = 29)	39.38±14.20	33.98-44.78	4	69.00	
Physician (n = 11)	34.91±12.68	26.39-43.43	17	61.00	
Resident physician (n = 20)	36.95±14.58	30.12-43.78	11	65.00	
Physical therapist (n = 32)	45.25±20.33	37.92-52.58	4	79.00	
Nursing technician (n = 49)	38.06±15.04	33.74-42.38	8	74.00	

95%CI = 95% confidence interval; SD = standard deviation.
* One-way analysis of variance for repeated measures.

Table 2 - Influence of way of handling on peak pressure and tidal volume for a total of 141 volunteers

Variables	Values	95%CI	Minimum	Maximum	p
Peak pressure (cmH_2O),					
mean ± SD					< 0.0001*
10 fingers	42.71±16.55	39.96-45.47	6.7	106.30	
Five fingers	42.71±13.75	37.47-42.05	6.5	89.20	
Four fingers	39.55±13.76	37.26-41.84	7.9	80.60	
Three fingers	39.50±14.62	37.07-41.94	2.5	105.30	
Two fingers	37.91±12.79	35.78-40.04	5.7	83.20	
Tidal volume (mL),					
median and quartile range					< 0.0001†
10 fingers	43.00, 30.00-52.00	38.56-44.13	8.00	88.00	
Five fingers	38.00, 29.50-51.50	36.87-42.25	4.00	79.00	
Four fingers	38.00, 25.00-51.00	36.00-41.12	8.00	74.00	
Three fingers	38.00, 25.00-51.00	36.14-41.03	8.00	65.00	
Two fingers	38.00, 25.00-51.00	35.27-40.73	4.00	74.00	

95%CI = 95% confidence interval; SD = standard deviation.
* One-way analysis of variance for repeated measures.
† Friedman's test.

Studies that compared the use of one or both hands, that is, five fingers and 10 fingers, respectively, during manual ventilation in adults, showed that the use of both hands resulted in higher tidal volumes.[8,15-18] However, Augustine et al.,[8] who also analyzed peak pressure, did not find statistically significant differences.

In the present study, we found high variability, with higher values of peak pressure and tidal volume than those recommended in the literature (peak pressure = 30-40 cmH_2O;[5,7,24] tidal volume = 5-10 mL/kg[7]). Similar findings were reported in two studies conducted by Rezende et al.[25,26] that assessed the performance of experienced neonatologists during lung ventilation. These studies evaluated peak pressure, respiratory frequency[25,26] and tidal volume.[26] In both studies, the authors found high variability of values for peak pressure[25,26] and tidal volume.[26] In addition to high variability, they also observed that the values were often higher than those recommended for neonatal resuscitation, with median (25-75% IQR) of 39.8 cmH_2O (30.2-47.2) and 17.8 mL/kg (14.1-22.4) for peak pressure and tidal volume, respectively. The authors pointed out that the technique was more adequate for respiratory frequency, which ranged between 30 and 60 cycles per minute in 65% of the cases.[26] In both studies, the relief valve remained locked, which may have contributed to the generation of higher pressures. In the present study, the valve remained in the position of adequate operation (unlocked) and, therefore, it should have released the excess of pressure when reaching 40 cmH_2O, although it did not happen. The use of the relief valve is discussed by Finer et al.,[27] whose study demonstrated high variability of pressure when the valve was activated. The authors also stated that these pressure values occasionally exceeded safe limits.

It should be acknowledged that the artificial lung used in the present study did not simulate the thoracic expansion of a newborn. The absence of this visual feedback might have affected the values produced by the professionals.

Based on the high variability and frequent occurrence of values not recommended for neonatal resuscitation, some authors suggest that the use of a manometer connected to the circuit may reduce the variability of the values provided by manual lung ventilation, making the procedure safer and, as a consequence, decreasing possible iatrogenesis.[28,29] Such an accessory device was not tested in the present study, since we consider that it is only able to record pressure values already delivered, without avoiding the variability of such values due to the different ways of handling of the self-inflating bag.

It should also be observed that a source of compressed gas was not used in the present study. Nevertheless, the use of a source of gas connected to a self-inflating bag with oxygen input directly inside the bag may have an important influence on the value of respiratory parameters.[30] Furthermore, ventilatory parameters may be affected by the use of a reservoir, and by the maximum capacity and compliance of the bag.

In the present study, we could not find influence of the profession on the values of peak pressure and tidal volume resulting from the use of manual lung ventilator. Although comparing professional groups, Hussey et al.[13] also failed to observe such a correlation. In their study, 35 health professionals were included and divided into two groups: physicians (n = 23) and other health professionals (n = 12) during manual ventilation in an intubated neonatal model. The authors did not find significant differences for any of the variables studied (peak pressure, respiratory frequency and positive end-expiratory pressure) between the groups ($p > 0.05$).

On the other hand, Finer et al.[9] studied 27 professionals (five respiratory therapists, four neonatologist, five pediatric resident physicians, five nurses, six physicians specialized in neonatology and two nursing practitioners) during manual ventilation (with a mask) in a neonatal model with two different types of circuits, and reported that respiratory therapists provided significantly higher pressures (peak pressure and positive end-expiratory pressure) than the other professional groups ($p < 0.0001$). Augustine et al.[8] found different results: the highest and lowest tidal volumes were provided by nurses and physicians working at the emergency room, respectively, while the highest and lowest peak pressures were generated by paramedics and respiratory therapists, respectively ($p < 0.05$).

The results of the present study indicate that some individuals provided very high peak pressure and tidal volume, which might increase the risk of barotrauma and volutrauma, particularly when both hands were used to ventilate. On the other hand, other professionals provided very low pressures and volumes, and, therefore, insufficient values for adequate lung expansion, causing risk of hypoventilation. Such risks were not dependent on the professional education.

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Correspondence:
Mariana A. Bassani
Serviço de Fisioterapia CAISM/UNICAMP
Rua Alexander Fleming, 1101
CEP 13083-970 - Campinas, SP - Brazil
Tel.: +55 (19) 3521.9511, +55 (19) 3521.9428, +55 (19) 3521.9483
E-mail: bassanimariana@hotmail.com