

Chest expansion for assessing tidal volume in premature newborn infants on ventilators

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Abstract

Objectives: To investigate whether clinical observation of chest expansion predicts tidal volume in neonates on mechanical ventilation and whether observer experience interferes with results.

Methods: An observational study that enrolled less experienced physicians in the first year of pediatric residency, moderately experienced (second year pediatric residency, first year of neonatology or pediatric intensive care specialization) or who were already experienced (second year neonatology specialization, graduate students or primary physician supervisors with minimum experience of 4 years in neonatology). These professionals observed the chest expansion of newborn infants on mechanical ventilation and estimated the tidal volume being supplied to the babies. True tidal volume given was calculated, indexed by the patient's current weight, and considered adequate between 4 and 6 mL/kg, insufficient below 4 mL/kg and excessive over 6 mL/kg. Results were analyzed using chi-square test.

Results: One hundred and eleven assessments were carried out with 21 newborn infants and the estimates given were in agreement with measured volume in 23.1, 41.3 and 65.7% for less, moderately and experienced physicians, respectively. These results are evidence that the three groups are not statistically equal ($p = 0.013$) and that the group of fully-experienced physicians have a better level of agreement than those with little or moderate experience ($p = 0.007$).

Conclusions: Clinical analysis of chest expansion by physicians with less or moderate experience exhibit a low level of agreement with the tidal volume given to newborn infants on mechanical ventilation. Although increased experience did result in higher levels of agreement, chest expansion must still be interpreted with caution.

J Pediatr (Rio J). 2007;83(4):329-334: Premature neonates, mechanical ventilation, tidal volume, chest expansion, lung injury, volutrauma, bronchopulmonary dysplasia.

Introduction

Mechanical pulmonary ventilation is one of the principal resources employed to support the life of patients who are suffering respiratory failure, but it contributes to start and worsen lung injury¹ and damage to distant organs, making it one of the factors responsible for increased morbidity and mortality, primarily among premature babies.²⁻⁴ Anatomical

peculiarities observed in these newborn infants predispose towards the occurrence of volutrauma during mechanical ventilation,⁵ which is the main trigger factor for ventilation-induced lung injury,^{6,7} which may result in the development of bronchopulmonary dysplasia (BPD).⁸

Based on volutrauma concept, it is recommended, in order to minimize lung damage during mechanical

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ventilation, to maintain strict control over the tidal volume provided, maintaining it between 4 and 6 mL/kg,^{9,10} although, in certain clinical situations, ventilation with volumes of up to 10 mL/kg may be necessary. In experimental studies this figure showed to be not as injurious as the use of large volumes.¹¹

Despite the importance of controlling tidal volume, the continuous flow type mechanical ventilator is the most frequently used during the neonatal period, pressure limited and time cycled, and therefore not limiting tidal volume.⁴ Therefore, for guidance and to determine the optimum inspired volume, very often clinical assessment of chest expansion is employed. Empirically, an increase in the height of the sternum of around 1/2 cm is considered adequate expansion.¹² Studies of pulmonary compliance based on chest expansion in newborn infants on mechanical ventilation have shown that the degree of correlation was determined by the examiner's ability and experience and that less experienced professionals were unable to correctly estimate respiratory system complacency.¹³⁻¹⁵

Based on this information, the study investigates whether clinical analysis of chest expansion by physicians is capable to predict the tidal volume resulting from pressure parameters used to ventilate neonates and whether their experience interferes in results.

Methods

This was an observational study carried out at the neonatal intensive care unit (ICU) at the Hospital São Paulo, Universidade Federal de São Paulo, Escola Paulista de Medicina, between July 2003 and June 2004, after approval by the Research Ethics Committee and granting of signed free and informed consent by the physicians and the guardians of the newborn infants included in the study.

Inclusion and exclusion criteria

During the data collection period a shift system was in effect at the nursery involving physicians in their first or second year of pediatric residency (R1 and R2, respectively); those who have already completed 2 years of pediatric residency and were in their first year of neonatology specialization (S3 Neo) or their first of pediatric intensive care specialization (S3 Ped ICU); those who were in their second year of neonatology specialization (S4), doctors taking graduate courses in neonatology with at least 4 years' experience in the area (PG) and primary physician supervisors with a minimum of 5 years' experience in neonatology. Figure 1 illustrates the total number of physicians who participated in the shift system at the nursery ward during the data collection period and the number of physicians who participated in the study. These professionals were classified according to degree of: less experienced (R1),

moderate experience (R2, S3 Neo and S3 Ped ICU) and experienced (S4, PG and primary physician supervisor). Within their respective experience categories, all of them showed a good level of agreement for tidal volume assessment.

As a result of the work routine at the unit, inclusion of physicians in this study depended on the shift system and on the availability of each physician when data was collected. For this reason, not all newborn infants were necessarily assessed by all professionals.

To be included newborn infants had to be inpatients at the Hospital São Paulo Neonatal ICU, be in the mechanical ventilation weaning phase, with extubation planned for within 72 hours and to be or not receiving analgesic medication at minimal doses. The study was only carried out when the investigator herself was present at the hospital. Baby exclusion criteria were congenital malformation, cardiorespiratory instability, failed tracheal extubation within 72 hours of data collection, parents and or professionals denying consent and impossibility to analyze pulmonary function curves to calculate tidal volume.

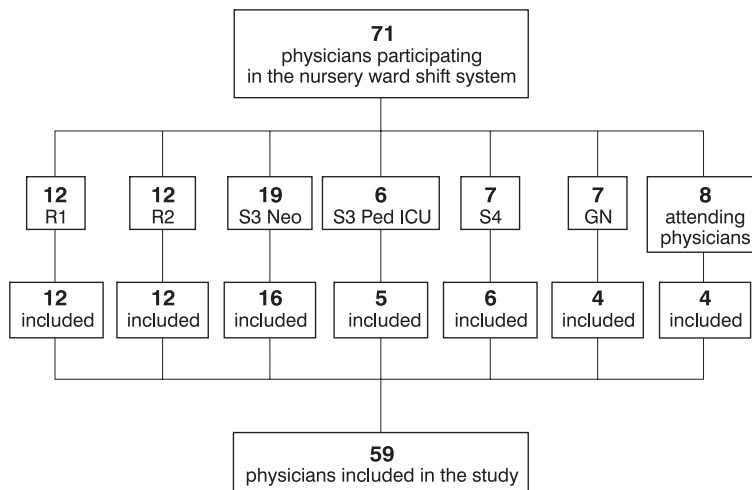
The time at which extubation took place was defined by the medical team depending on the clinical and laboratory conditions of child. All of the patients were ventilated with continuous flow equipment, limited by pressure and time cycled, in intermittent mandatory ventilation or controlled mandatory ventilation modes. Neither mechanical ventilation parameters nor any other intervention related to the treatment of children was modified for data collection.

Data collection

Once inclusion criteria had been met, and one hour before valuations were conducted, tracheal aspiration was performed if it was possible to see secretions in the cannula or if pulmonary auscultation suggested the presence of pulmonary secretions; if condensed water was present in the ventilator circuit this was removed. Furthermore, a minimum 1-hour period was defined between infusion enteral diet and the evaluation.

The correct positioning of the tracheal cannula was ascertained by symmetrical auscultation of vesicular murmur in both hemithorax, by observing the scale in centimeters on the cannula at the upper lip, which was maintained according to the rule of the child weight plus 6,¹⁶ and by chest X ray, where the tip of the cannula was kept between the first and third thoracic vertebrae.

With the newborn on its back and with the head in a neutral position, a pneumotachograph with fixed area and dead space of 0.8 mL, was fitted between the ventilator circuit and the cannula. Flow signals were read every 25 ms by the graphical monitor (Tracer 5, Intermed[®]), which has a built in



S3 Neo = first year of neonatology specialization; S3 Ped ICU = first year pediatric intensive care specialization; S4 = second year of neonatology specialization; GB = graduate course in neonatology with at least 4 years of experience in the area; R1 = first year pediatric resident; R2 = second year pediatric resident.

Figure 1 - Total number of participant physicians in the shift system at the nursery ward during data collection period and numbers of physicians included in the study

flow self-calibration system. In addition to this system, manual calibration was carried out periodically before each study in accordance with the manufacturer's instructions, since calibration could significantly influence the results of the study.¹⁷

Pressure, flow and volume curves were stored in a microcomputer, and analyzed later using software (Wintraccer, Intermed®).

Next, the health professionals on duty at the unit began their clinical assessment. Each physician was instructed to take a maximum of 2 minutes to report whether or not tidal volume was adequate according to chest expansion. Expansion was defined as adequate middle third of the sternum was observed to rise by around 1/2 cm. If the movement was less or greater than this amount, then expansion was defined as inadequate or excessive, respectively.¹²

After the observation period, the health professional was given a card with the following question, "After observing the clinical parameters of the baby, do you believe that the tidal volume supplied to this baby is adequate?" If the reply was negative, the physician specified whether the tidal volume was insufficient or excessive. The response was given by each observer and kept secret, so that neither the investigator nor other professionals participating in the study knew what the reply was. To this end, the cards containing their replies were sealed in an envelope and identified with the protocol and the level of experience of the professional who made the assessment, and opened only at the end of the study.

Immediately after the clinical assessment, the tidal volume provided by the ventilator was measured using the pneumotachograph. None of the professionals making the clinical assessments had access to this procedure. Signals were captured for 10 minutes, or until 10 controlled respiratory cycles had been obtained with a clear signal. These signals were stored in the computer every 10 seconds by the Wintraccer software, which calculated that tidal volume measurement every minute during the study period. For purposes of the study, mandatory expired tidal volume was calculated from curves where the inspiratory flow was zero for a minimum of 50 ms before expiration began, guaranteeing complete inflation of the lungs. The final tidal volume measurement was defined as the mean of 10 controlled respiratory cycles indexed by the current weight of the patient. All data were collected by a single research with experience in identifying flow curves and excluding cycles with artifacts, with air leaks and with spontaneous cycles superimposed on the respirator cycle.

These measurements were recorded and remained known only to the researcher, and were not revealed at any point to any of professionals participating in clinical assessment of the patients.

The newborn infants had to remain calm and comfortable throughout the assessment period and in the event of any sign of clinical deterioration, such as alterations to oxygenation or hemodynamic conditions, monitoring was stopped. Neither administration nor doses of analgesic medications were modified for data collection.

Statistical analysis

Database was created containing the flow curves for each newborn and the calculations of their tidal volume. The results obtained were compared with the assessments made by the doctors as a group and by categories (little experience, moderate experience and experienced).

For result analysis, the tidal volume measured by the monitor (gold standard) was considered adequate when between 4 and 6 mL/kg.

The health professionals' replies and the volumes reported by the monitor, classified as adequate insufficient or excessive, were associated in order to calculate assessments in agreement and proportion of agreements between the professionals and the instrument.

The chi-square test with two degrees of freedom was employed to compare the groups of doctors.

Results

The physicians performed 115 assessments of the 22 children studied. One child, who underwent four clinical assessments, was excluded because it was impossible to obtain curves from which to calculate tidal volume. Therefore, 111 assessments of 21 children were analyzed. The professionals with little experience made 13 assessments, the moderately experienced made 63 and the experienced physicians made 35 assessments.

The 21 newborn infants included in the study had a mean gestational age of 30.5 ± 3.21 weeks, mean postnatal age of 186.4 ± 179.9 hours of life and mean weight on the day of assessment of 1391 ± 75 g. Mean tidal volume was 7.6 ± 4.13 mL/kg. All had been intubated in the delivery room with cannulae of uniform diameter varying from 2.5 to 3.5. Seventeen of these (81%) were ventilated because of respiratory distress syndrome and four (19%) for early stage adaptive respiratory distress. The principal intercurrent clinical conditions observed by the start of the study were: nine cases of persistent ductus arteriosus, six of peri-intraventricular hemorrhage (four class I, one class II and one class III) and two convulsions.

Four (19%) of the 21 children included in the study were being ventilated within adequate limits, one (4.8%) at a tidal volume smaller than 4 mL/kg and 16 (76.2%) with tidal volumes of more than 6 mL/kg.

The replies given by the physicians with little experience agreed with the tidal volume measured by the monitor in just three (23.1%) of the 13 assessments they performed. In all of the assessments that agreed, the tidal volume provided by the mechanical ventilator was within the range of 4 to 6 mL/kg.

The doctors with moderate experience achieved agreement in 11 assessments where the volume provided by the ventilator was within the stipulated limits and 15 where the tidal volume provided was above the limits established, making a total of 26 (41.3%) assessments in agreement out of 63.

The experienced physicians achieved 65.7% of agreement with the tidal volume measured by the monitor. This category of doctor agreed with the tidal volume in 23 out of 35 assessments. In five of these the volume of gas measured by the monitor was adequate and, in the other 18, the volume was excessive. All of the replies given by the professionals were related to the measurements of tidal volume made by the monitor, as shown in Table 1.

The chi-square test with two degrees of freedom was used to compare the replies given by the three groups of physicians (Table 2). The chi-square value found was 8.74, which demonstrates that the three groups are not equal ($p = 0.013$). Next an orthogonal partition of the chi-square was undertaken, which produced two tables, each with one degree of freedom; the value of chi-square thus obtained was 1.511, which is statistical evidence of the same level of agreement between physicians with less and moderate experience ($p = 0.219$) and greater agreement for the group of experienced physicians, with a chi-square value of 7.308 and $p = 0.007$.

Discussion

The results of this study have demonstrated that, when performed by physicians still in training, clinical assessment of chest expansion to estimate tidal volume provided to newborn infants on mechanical ventilation is less precise. While increasing experience did result in better levels of agreement, chest expansion should still be interpreted with caution.

Based on the concept that ventilation strategies that employ high tidal volumes are more injurious (volutrauma¹⁸), current recommendations are strict control of the volume of gas provided during mechanical ventilation. The volumes stipulated are between residual functional capacity and total lung capacity, between 4 and 6 mL/kg,^{9,10} and recruit without over inflating terminal airways, making them appropriate for ventilating newborns. Despite this, in our country, in the majority of neonatal ICUs, the use of continuous flow ventilators, pressure limited and time cycled, still rules. With these apparatus, the volume of gas provided depends on the pressure gradient and, primarily, on the impedance of the respiratory system, i.e., on the behavior of complacency and resistance. It is known that these variables undergo constant changes during the first hours after birth, meaning that the volume of gas administered at each inspiration is highly variable.

Table 1 - Frequency of correct replies given by the health professionals in each category and the tidal volume measured by the monitor

Doctor's assessment	Monitor			Total
	Insufficient	Adequate	Excessive	
Little experience				
Insufficient	0*	1	2	
Adequate	1	3*	6	
Excessive	0	0	0*	13
Moderate experience				
Insufficient	0*	2	5	
Adequate	3	11*	25	
Excessive	0	2	15*	63
Experienced				
Insufficient	0*	1	1	
Adequate	1	5*	8	
Excessive	1	0	18*	35

* p = 0.219 by the chi-square test.

Table 2 - Final frequency of correct answers for the health professionals studied

Physician	Agreement with monitor		
	Yes	No	
Less experience	3 (23.1%)*†	10 (76.9%)	13
Moderate experience	26 (41.3%)*†	37 (58.7%)	63
Experienced	23 (65.7%)*†	12 (34.3%)	35
Total	52 (46.8%)	59 (53.2%)	111

p = 0.013 by the chi-square test.

* p = 0.219 by the chi-square test.

† p = 0.007 (doctors with less and moderate experience compared with experienced ones) by the chi-square test.

In everyday practice, with mechanical ventilation, clinical assessment of chest expansion is used in order to define the settings for tidal volume very often. Empirically, a rise of around 1/2 cm of the sternum is considered good expansion. Employing this criterion, this study demonstrated that agreement level exhibited by professionals with less or moderate experience was lower when compared to experienced physicians. These findings are similar to those of studies which have assessed pulmonary compliance

calculated from tidal volume estimated by chest expansion in newborn infants on mechanical ventilation. There, results demonstrated that the agreement level was determined by the ability and experience of the observer and that less experienced health professionals were unable to correctly estimate respiratory system complacency.¹³⁻¹⁵

Furthermore, it was also noted that the majority of assessments did not agree with the tidal volume measured,

under estimating the volume of gas provided, in other words, the tidal volume provided was excessive but clinical assessment defined it as appropriate. Since the newborn infants included in this study were in the phase of weaning off mechanical ventilation, approaching extubation, the underlying lung disease was already in the process of resolution, with pulmonary compliance normalized. Therefore this finding is in agreement with the literature,¹⁵ which provides evidence that complacency is over estimated in damaged lungs, whereas it is underestimated in lungs with little or no injury.

Despite the limitations of observational studies, such as standardization of the number of professionals in each experienced category and the difficulty of performing statistical calculations, the results of this study suggest that visual assessment of chest expansion on mechanical ventilation may not be sufficiently sensitive to detect small variations in tidal volume, even when performed by experienced health professionals. This fact becomes more evident in very low birth weight preterm infants, where the margin for tidal volume adjustment is very narrow, i.e., between 5 and 7 mL.

It has been demonstrated that, in clinical practice, pulmonary function tests carried out during mechanical ventilation do not offer increased benefits and that assessments carried out by physicians with little experience have little correlation with measured pulmonary compliance.¹⁹

We believe that it is recommendable, particularly for very low birth weight preterm infants, to continuously monitor the tidal volume provided during mechanical ventilation in order to reduce injuries resulting from volutrauma.

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