



A comparison of the continuous positive airway pressures produced by two systems

Marcela Raquel de Oliveira Lima,¹ Ana Lúcia de Gusmão Freire,²
Livia Barboza de Andrade,³ Leopoldino Gomes Santos⁴

Abstract

Objective: To compare the generation of continuous positive airway pressure using a hand-made device (underwater seal) or a ventilator (Inter 3[®]).

Method: Two positive airway pressure generation systems were compared through laboratory simulations. Measurements were not considered if the mechanical ventilator required calibration or in the presence of gas flow variation (flowmeter sphere oscillation). Recordings were assessed in terms of the capacity to produce the desired pressure (3, 5 and 6 cmH₂O) when submitted to three different flow values (8, 10 and 12 l/min). For that end, Student's t test for paired samples and the nonparametric Man-Whitney test for independent samples were employed.

Results: We verified that the systems behave in different manners under the same conditions of flow and positive end expiratory pressure. For the mechanical ventilator, the mean pressure behavior under continuous positive airway pressure at 3 cmH₂O with flows of 8, 10 and 12 l/min were 2.26±0.41, 2.22±0.37, 2.04±0.41, respectively; under positive end-expiratory pressure at 5 cmH₂O we found 3.96±0.41, 3.87±0.43 and 3.75±0.52; and under positive end-expiratory pressure at 6 cmH₂O the values recorded were 4.94±0.40, 4.85±0.41 and 4.72±0.37. For the underwater seal, the mean pressure behavior under continuous positive airway pressure at 3 cmH₂O with flows of 8, 10 and 12 l/min were 4.24±0.24, 4.46±0.26, 4.72±0.37, respectively; at 5 cmH₂O the values were 5.97±0.17, 6.28±0.18, 6.47±0.31; and at 6 cmH₂O we recorded 6.85±0.20, 7.17±0.29 and 7.53±0.31. All the comparisons were statistically significant (p = 0.000).

Conclusion: Through our recordings it was possible to observe that the Inter 3[®] continuous positive airway pressure system was more stable than the underwater seal.

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Introduction

Pulmonary disorders constitute an important cause of neonatal morbidity and mortality, although with advances in intensive care techniques, better results are being observed in disease treatment and in improved clinical progress.

Against this background, the importance of respiratory care must be acknowledged as the primary determinant of these changes.¹⁻³ Many different types of ventilatory support for newborns are available, all with the objective of optimizing gas exchange and reduce respiratory effort. One of these types is continuous positive airway pressure (CPAP), which is a non-invasive resource, easily manipulated and with fewer complications than invasive mechanical ventilation.^{1,4,5}

Continuous positive airway pressure could be defined as an artificial system for generating positive transpulmonary pressure during spontaneous respiration thus affording an increase in residual functional capacity (RFC), which is extremely important for newborn babies since it functions as an oxygen reservoir during those periods when there is no inward airflow, such as when crying or feeding, in addition to impacting on respiratory workload.⁵⁻¹⁰

1. Physical therapist, Pulmocárdio, Recife, PE, Brazil.
2. Physical therapist, specialist in child disorders. Professor, Universidade de Ciências da Saúde de Alagoas (Uncisal), Maceió, AL, Brazil.
3. Specialist in cardiorespiratory physical therapy, Universidade Federal de Pernambuco (UFPE). Graduate student in Physiology, UFPE. Professor, Faculdade Integrada do Recife (FIR), Recife, PE, Brazil.
4. Electric engineer, Kesa/Intermed[®], Recife, PE, Brazil.

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For many years, nasal CPAP was reserved for mild to moderate hyaline membrane disease, in larger preterms.^{5,11} However, CPAP is coming to be employed as a successful therapy in around 37% of newborn babies weighing less than 1,000g, in 59% of newborn babies with weights between 1,000 and 1,500g and in 83% of preterms weighing more than 1,500 g.^{11,12} The use of CPAP with very low birth weight preterm newborn babies is, in fact, debatable. Nowadays the possibility of exogenous surfactant exists, and these newborns could benefit from a brief period of intubation for surfactant administration, followed by nasal CPAP, thus avoiding the risk of prolonged positive pressure ventilation.^{2,4,7,12-14}

Continuous positive airway pressure increases oxygenation without increasing alveolar ventilation, because it promotes the re-expansion of previously collapsed parts of the lung, reducing intrapulmonary shunt and increasing the gas exchange surface area and thus improving the ventilation-perfusion ratio.¹⁵

There are, basically, two systems for generating CPAP; the type incorporated into mechanical ventilators (MV) with each manufacturer having its own characteristics, and the handmade system (water seal). Both require a continuous flow generator, a system for connecting to the patient's airway and a device to generate positive pressure.^{5,7,9} Short binasal prongs and with little airflow resistance (greater internal diameter) are the simplest method for offering CPAP and produce the best therapeutic effects, despite presenting some disadvantages such as fixation difficulties, pressure loss during crying and trauma to the nasal septum.^{2,5,16,17} Endotracheal CPAP is less often used, since, despite being a safe method for maintaining average airway pressure (P_{aw}) and to control the fraction of inspired oxygen (FiO_2), it presents the disadvantages associated with tracheal intubation, in addition to creating airflow resistance, which could increase respiratory workload.¹⁷⁻²¹

When CPAP is offered with a ventilator, the gas supplies are part of the apparatus and flow rate and FiO_2 are adjusted with specific devices for each parameter, while positive pressure is offered by an expiratory circuit on the mechanical ventilator.^{5,22} With, homemade CPAP, also known as water-seal CPAP, flowmeters are used on the compressed air and oxygen supplies, with the total flow being worked out from their sum and controlling FiO_2 by means of their relative proportions in the mixture. The distal end of the expiratory circuit is submerged in a receptacle containing water the level of which in centimeters corresponds to the positive end expiratory pressure (PEEP).^{5,7}

The existence of two systems routinely used to offer CPAP in Neonatal Intensive Care Units triggered an interest in comparing them, since it is believed that they offer the same mechanical conditions. The objective of this study was to compare the continuous positive airway pressure generation of a handmade system (water seal) with a system integrated into a mechanical ventilator (Inter 3®).

Methods

Two systems for generating CPAP were analyzed. One was supplied by an Inter 3® (Intermed – São Paulo) neonatal mechanical ventilator programmed for CPAP mode and the other was a handmade water seal system. The experiment was performed at the maintenance laboratory at KESA (KESA *Comércio e Serviços Ltda.*), with the support of Intermed.

The research project was approved by the Committee for Ethics in Research at the Universidade Federal de Pernambuco (UFPE) Health Sciences Center, in accordance with resolution 196/96 of the *Conselho Nacional de Saúde* (CNS).

Recordings during which ventilator decalibration had been detected were discarded as were those made when there had been variation in piped gas flow (flowmeter bulb). Additionally, for increased reliability of results, we took the precaution of always making recordings with the same mechanical ventilator.

Laboratory simulated controlled experiments were performed and studied. It was necessary to develop prototypes of the two systems that would simulate conditions similar to those encountered with nasal CPAP (water seal and Inter 3®) as used with newborns (Figures 1 and 2).

Continuous recordings were made of sixty seconds' duration in order to analyze the behavior of average pressure (P_A), at flow rates of 8, 10 and 12 l/min, combined with PEEP of 3, 5 and 6 cmH₂O. Based on the sample-size calculation, it was determined that at least eight samples were needed for each system. Ten recordings were therefore made for each preadjusted pressure and flow combination, i.e. 90 recordings for each system.

In order to compare the two systems, two similar prototypes were employed to conduct the gas flow required to the binasal prong (Hudson®, nº 1) via the inspiratory limb of the circuit. The binasal has two anterior projections, each around 1 cm long, which were used separately; one of the passages allowed $\leq 20\%$ of the total gas flow to escape (bearing in mind that the nasal CPAP technique allows leakage around the baby's nostrils and/or mouth), while to the other nozzle a fixed resistance of 30 cmH₂O/l/s was applied (to simulate the neonatal airway^{20,22}) and a test lung were connected.

A Timeter® (Respical by allied healthcare products, Inc.) was used to record average pressure (P_A), sensing pressure at the distal portion of the prong, before the expiratory limb. The Timeter® passed the signal to a software package (Respical by allied healthcare products, Inc.), which amplified the recording, allowing the graphical behavior of the pressure circuit to be viewed in real time, in addition to informing the numerical values for P_A , minimum pressure (P_{min}) and maximum pressure (P_{max}) generated by the CPAP systems.

The Inter 3® and water seal CPAP systems have different flow and pressure generators. On the Inter 3® CPAP (Figure 1), flow rate (8, 10 and 12 l/min) and PEEP (3, 5, 6 cmH₂O) are adjusted on the machine itself. With the water-seal

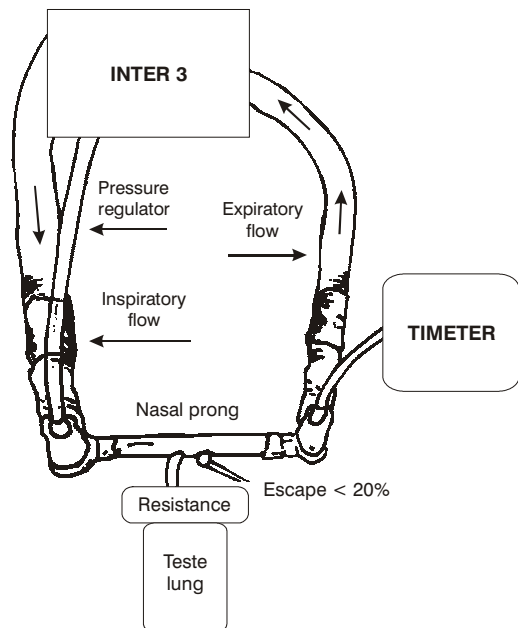


Figure 1 - CPAP prototype in Inter 3®

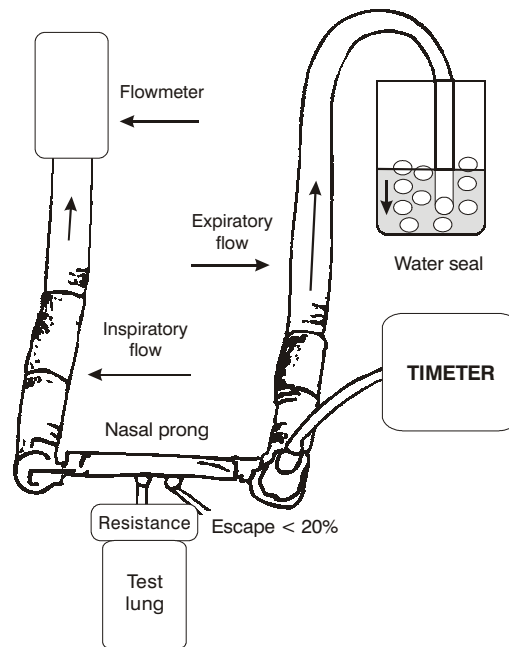


Figure 2 - CPAP prototype in water seal

CPAP system (Figure 2) the same flow rates were generated by a wall-mounted flowmeter (White Martins, 15 l/min – calibrated to 3.5 kgf/cm² – 21°) and PEEPs by a water seal produced with a 500 ml capacity mediastinal drainage collector (14 cm long with 6 cm diameter), filled with water up to level at which the inner tube (12 cm long with a 1 cm diameter) was submersed in the water column sufficiently to produce the desired PEEP, i.e. each centimeter of the water column corresponded to 1 cm of water (cmH₂O) of expiratory pressure (PEEP). Throughout the experiment, gas temperature was maintained at 27 °C and room temperature was 26 °C.

Recordings were assessed in terms of the capacity to generate the desired pressures when subjected to three different flow rate values. To this end Student's t test for a single sample was applied, i.e. we tested the average pressure values obtained against the predetermined pressures. Since neither system performed as expected, the Mann-Whitney parametric independent sample test was applied in order to test the differences in the pressures generated by the two systems. All tests were analyzed at 99% confidence, accepting $p \leq 0.001$. The software used for analysis was SPSS version 8.0 for the statistical tests described, and Excel 97 for rendering the diagrams.

Results

The results of this study show that the two systems behave differently under identical flow and PEEP conditions. The behavior of average, maximum and minimum pressure is described in Tables 1, 2 and 3, respectively.

When the recordings obtained from the Timer for the Inter 3® and water seal systems, we found that they did not only differ in terms of P_A maintenance, but also exhibited distinct behavior in terms of the pressure against time relationship (Figure 3). Furthermore, during our experiments we observed that the large variations in pressure that occurred with the water seal CPAP created vibrations in the test lung, which could be compared to those produced by high-frequency ventilation, which is a form of mechanical ventilation based supplying small tidal volumes and high respiratory frequencies.

Discussion

We observed that the pressures analyzed (P_A, P_{max} and P_{min}) behaved differently both quantitatively and qualitatively. The water seal CPAP produced higher pressure levels than expected in all recordings and, furthermore, when higher flow rates were used, P_A

increased. The Inter 3[®] CPAP, in contrast, consistently generated lower P_A values than those set on the apparatus and exhibited a tendency to reduce as progressively higher flow rates were used. This difference, however, between the pressure selected on the Inter 3[®] and that measured at the Timeter[®] may be considered to be a probable result of the fact that the ventilator controls pressure in the proximal portion of the prong (after the inspiratory limb), while the Timeter[®] reproduced the pressure at the distal portion of the prong, where it was connected. The pressure loss that occurred may be related to the resistance of the circuit between the two points of measurement and the permissible gas leakage, since we are looking at partially closed systems. Additionally, there is a range of variation that is considered

tolerable for the equipment's calibration, i.e. ventilators may produce pressures that are discretely greater or smaller than those displayed on the electronic manometer.

The P_A produces by both the Inter 3[®] and the water seal suffered the influence of a number of different variables, such as, for example: the size of the nasal prongs which impact on air-flow resistance, airway resistance, which is related to the pathological status of the newborn, the fit of the nasal prongs within the nostrils, which will cause more or less gas to escape and leaks in the circuit or at the flowmeters.

Our records also show that the Inter 3[®] CPAP behaved in an almost static manner with a small band of variation in pressure levels (less than 1 cmH₂O), probably because the

Table 1 - Comparison of the mean pressures obtained from both systems

	8 l/min		10 l/min		12 l/min	
	Hand-made device	Mechanical ventilator	Hand-made device	Mechanical ventilator	Hand-made device	Mechanical ventilator
3 cmH ₂ O	4.24±0.24	2.26±0.41 *	4.46±0.26	2.22±0.37 *	4.72±0.37	2.04±0.41 *
5 cmH ₂ O	5.97±0.17	3.96±0.41 *	6.28±0.18	3.87±0.43 *	6.47±0.31	3.75±0.52 *
6 cmH ₂ O	6.85±0.20	4.94±0.40 *	7.17±0.29	4.85±0.41 *	7.53±0.31	4.72±0.37 *

* $p < 0.001$ with statistically significant difference.

The values are presented in mean and standard deviation (M±SD).

Table 2 - Comparison of the maximal pressure values obtained in both systems

	8 l/min		10 l/min		12 l/min	
	Hand-made device	Mechanical ventilator	Hand-made device	Mechanical ventilator	Hand-made device	Mechanical ventilator
3 cmH ₂ O	10.33±0.55	2.60±0.46 *	12.48±0.85	2.51±0.36 *	13.32±0.77	2.37±0.49 *
5 cmH ₂ O	11.81±0.88	4.53±0.41 *	13.52±0.75	4.45±0.45 *	14.76±0.87	4.38±0.51 *
6 cmH ₂ O	12.40±1.26	5.50±0.43 *	13.94±1.13	5.40±0.43 *	14.95±1.16	5.31±0.31 *

* $p < 0.001$ with statistically significant difference.

The values are presented in mean and standard deviation (M±SD).

Table 3 - Comparison of the minimal pressure values obtained in both systems

	8 l/min		10 l/min		12 l/min	
	Hand-made device	Mechanical ventilator	Hand-made device	Mechanical ventilator	Hand-made device	Mechanical ventilator
3 cmH ₂ O	0.73±0.56	1.92±0.34 *	0.44±0.56	1.89±0.38 *	0.70±0.69	1.72±0.50 *
5 cmH ₂ O	2.09±0.43	3.92±0.41 *	2.16±0.54	3.82±0.45 *	2.00±0.58	3.74±0.51 *
6 cmH ₂ O	2.78±0.64	4.87±0.39 *	3.17±0.38	4.77±0.40 *	2.84±0.51	4.63±0.38 *

* $p < 0.001$ with statistically significant difference.

The values are presented in mean and standard deviation (M±SD).

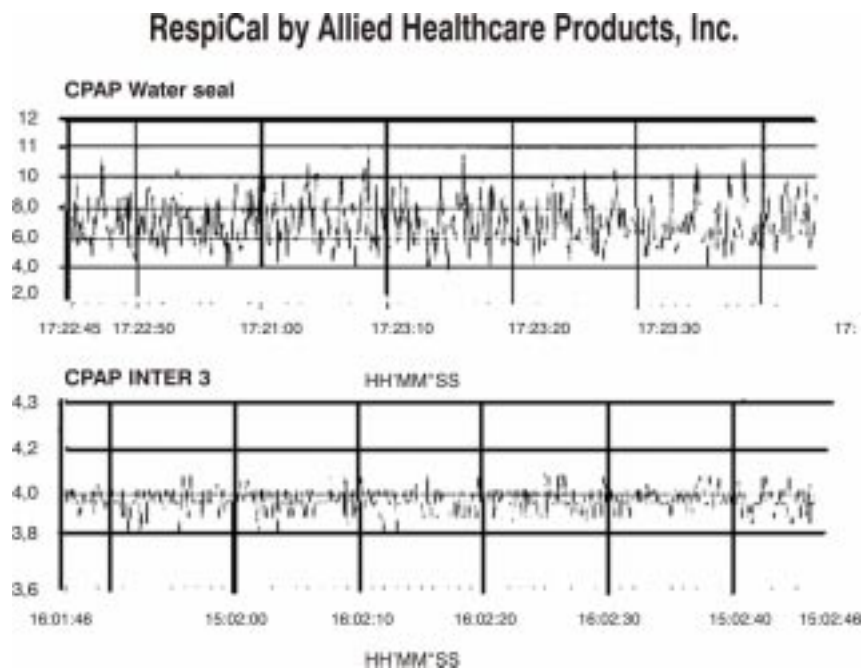


Figure 3 - Recordings of the pressures in the water seal and Inter 3[®] obtained from the Timeter

PEEP generation system in the Inter 3[®] uses a variably resistant valve, which allows for the pressure to be maintained relatively and makes the system safer and more stable. The water seal CPAP exhibited dynamic behavior, with a wide range of pressure value variation (around 2 to 4 cmH₂O), which was probably caused by bubbling in the water column, generating constant variations, producing changing resistance to airflow and impacting on PEEP. This difference would perhaps have been more easily apparent had the recordings been plotted on the same scale graphically, however the software employed does not allow pressure scales to be adjusted, calculating them automatically.

The waveform (pressure against time) produced by the water seal CPAP is similar to that produced by high-frequency ventilation.²² This last has been considered to be a ventilation mode with advantages over conventional mechanical ventilation in certain clinical situations, proving efficient at CO₂ elimination and capable of reducing the duration of ventilatory support and oxygen therapy because it makes use of different gas transport mechanisms than does conventional mechanical ventilation.^{21,22} Lee et al., studying newborn babies, observed vibrations similar to those found in our study. They state that the vibrations produced by the water seal CPAP's bubbling are transmitted

to the chests of the babies on this type of ventilatory support and could contribute to gas exchange.⁸ The mechanism by which gas exchanges occur during high-frequency ventilation have not been completely explained, but they probably include direct ventilation of the proximal alveoli and increased diffusion because of the increased activity of the gas molecules or even by means of coaxial diffusion in which the air enters via the center and the CO₂ and other gasses are exhaled via the peripheries of the airways.^{1,21,22}

Final considerations

While water seal CPAP is a low-cost means for us to apply continuous positive airway pressure, there do perhaps exist times at which the risks inherent in this type of CPAP become elevated, promoting the developments of undesirable effects and/or complications such as the air leak syndrome. For the same reasons, the Inter 3[®] CPAP appears to be a safer method, although, under certain circumstances it could become a less effective therapy. In addition to this we cannot omit the consideration that at many neonatal intensive care units there is not a ventilator available for every newborn that requires nasal CPAP, which encourages the use of water seal CPAP.

We were able to observe from our recordings that the Inter 3[®] CPAP behaved in a more stable and linear manner than did the water seal CPAP, which exhibited large variations in pressure. We therefore attempt to draw attention to the need for further studies which deal with the behavior of these pressures in the respiratory system of newborns in order that it becomes possible to deliver the necessary care ever more efficiently.

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Corresponding author:
Livia B. Andrade
Rua do Futuro, 17/1002
CEP 52050-010 - Recife, PE
Brazil
E-mail: livia@fir.br