Original Article

Adapting the Bird Mark 7 to deliver noninvasive continuous positive airway pressure: a bench study*

Adaptação do Bird Mark 7 para oferta de pressão positiva contínua nas vias aéreas em ventilação não-invasiva: estudo em modelo mecânico

Beatriz Mayumi Kikuti[1], Karen Utsunomia[1], Renata Potonyacz Colaneri[1], Carlos Roberto Ribeiro de Carvalho[2], Pedro Caruso[3]

Abstract

Objective: To test the efficiency of the Bird Mark 7 ventilator adapted to deliver continuous positive airway pressure (CPAP) in noninvasive positive pressure ventilation. **Methods:** This was an experimental study using a mechanical model of the respiratory system. A Bird Mark 7 ventilator was supplied with 400 and 500 kPa and tested at CPAP of 5, 10 and 15 cmH_2O. The following variables were analyzed: difference between the preset CPAP and the CPAP actually attained CPAP (trueCPAP); area of airway pressure at the CPAP level employed ($AREA_{CPAP}$); and tidal volume generated. **Results:** Adapting the Bird Mark 7 to offer CPAP achieved the expected tidal volume in all situations of inspiratory effort (normal or high), ventilator pressure supply (400 or 500 kPa) and CPAP value (5, 10 or 15 cmH_2O). At a CPAP of 5 or 10 cmH_2O, the trueCPAP was near the preset level, and the $AREA_{CPAP}$ was near zero. However, at a CPAP of 15 cmH_2O, the value remained below the preset, and the $AREA_{CPAP}$ was high. **Conclusion:** The efficiency of Bird Mark 7 adaptation in offering CPAP was satisfactory at 5 and 10 cmH_2O but insufficient at 15 cmH_2O. If adapted as described in our study, the Bird Mark 7 might be an option for offering CPAP up to 10 cmH_2O in areas where little or no equipment is available.

Keywords: Ventilators, mechanical; Positive-pressure respiration; Continuous positive airway pressure.

Resumo

Objetivo: Testar a eficiência da adaptação do ventilador Bird Mark 7 para oferecer pressão positiva contínua nas vias aéreas, conhecida como *continuous positive airway pressure* (CPAP) em inglês, em ventilação não-invasiva. **Métodos:** Estudo experimental utilizando um modelo mecânico do sistema respiratório. O Bird Mark 7 foi alimentado com 400 e 500 kPa e foi testado em CPAP de 5, 10 e 15 cmH_2O. Para avaliar a eficiência da adaptação foram analisados os seguintes variáveis: diferença entre a CPAP pré-determinada e a CPAP realmente atingida (CPAPreal); área da pressão da via aérea sob o nível de CPAP ajustado ($ÁREA_{CPAP}$); e volume corrente gerado. **Resultados:** A adaptação do Bird Mark 7 para oferecer CPAP em ventilação não-invasiva conseguiu atingir o volume corrente esperado em todas as situações de esforço inspiratório (normal ou elevado), pressão de alimentação (400 ou 500 kPa) e valor de CPAP (5, 10 ou 15 cmH_2O). Para os CPAPs de 5 e 10 cmH_2O, o CPAPreal foi muito próximo do pré-determinado, e a $ÁREA_{CPAP}$ teve valor próximo de zero. Para o CPAP de 15 cmH_2O, o CPAP real ficou abaixo do pré-determinado, e a $ÁREA_{CPAP}$ teve valor elevado. **Conclusão:** A eficiência da adaptação do Bird Mark 7 para oferecer CPAP em ventilação não-invasiva foi boa para os valores de CPAP de 5 e 10 cmH_2O e insuficiente para CPAP de 15 cmH_2O. Se adaptado como em nosso estudo, o Bird Mark 7 pode ser uma opção para oferta de CPAP até 10 cmH_2O em locais onde equipamentos de ventilação não-invasiva são escassos ou inexistentes.

Descritores: Respiradores mecânicos; Respiração com pressão positiva; Pressão positiva contínua nas vias aéreas.

Introduction

Continuous positive airway pressure (CPAP) is the simplest form of noninvasive ventilation (NIV). Its efficiency has been proven in various situations of respiratory insufficiency, such as acute pulmonary edema and chronic obstructive pulmonary disease.[1-4] The CPAP mode can be offered by different equipment, such as ventilators for

* Study carried out in the Laboratory of Pulmonary Mechanics (LIM09), Department of Pulmonology, University of São Paulo School of Medicine, São Paulo, Brazil.

1. Medical student. University of São Paulo School of Medicine, São Paulo, Brazil.
2. Associate Professor. Pulmonology Department, University of São Paulo School of Medicine, São Paulo, Brazil.
3. Attending Physician in the Respiratory Intensive Care Unit of the University of São Paulo School of Medicine *Hospital das Clínicas* – São Paulo, Brazil.
Correspondence to: Pedro Caruso. Avenida Dr. Eneas de Carvalho Aguiar, 255, Sala 7079, Secretaria da Pneumologia, Cerqueira Cesar, CEP 05403-000, São Paulo, SP, Brasil.
Tel 55 11 3069-7578. E-mail: pedrocaruso@uol.com.br

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invasive ventilation adapted to deliver NIV, specific ventilators for NIV and continuous flow generators Unfortunately, equipment used specifically for NIV is unavailable in many hospitals, especially those located in disadvantaged areas. A recent study showed that, in the metropolitan area of the city of São Paulo, Brazil, ventilators for invasive ventilation adapted to deliver NIV prevail.[6]

The Bird Mark 7 ventilator is cheaper than the conventional ventilators. It does not require electricity and is fairly common in the Brazilian hospitals. Many professionals have, empirically, adapted the Bird Mark 7 to offer NIV in CPAP mode.[7] However, the efficiency of this adaptation has never been studied. Knowledge of the proper way to make this adaptation and comparisons between its performance and that of specific NIV equipment might benefit patients in hospitals where equipment to deliver CPAP is not available.

The objective of this study was to test the efficiency of the Bird Mark 7 in offering NIV in CPAP mode.

Methods

The study was conducted in a mechanical model of the respiratory system in which two bellows were interconnected (Adult TTL 2600; Michigan Instruments, Grand Rapids, MI, USA). The model was modified in relation to those used in previous studies.[8,9] A standard ventilator for VNI was used (Bear V; Bear-Viasys, Riverside, CA, USA) in order to simulate the inspiratory pressure. It was connected to one of the bellows, for which the compliance was set to 100 mL/cmH_2O. The insufflation of the first bellows by the triggering ventilator generated negative pressure in the second bellows, for which the compliance was set to 50 mL/cmH_2O. The second bellows was connected to a life-size mannequin head (C500; Kapta, Sao Paulo, Brazil) fitted with tubes simulating the size and the resistance of the upper airways. A facial mask (9000C5; Vital Signs, Totowa, NJ, USA) was attached to the face of the mannequin, and connected to the Bird Mark 7 ventilator (Viasys Healthcare, Palm Springs, CA, USA).

A pressure transducer (DP45-30; Validyne, Northridge, CA, USA) simulating the upper airway pressure was connected to the upper airways of the mannequin. A pneumotachograph (Flow Head 3700; Hans Rudolph, Kansas City, MO, USA) was also connected to the airways of the mannequin in order to measure the inspiratory flow and obtain the tidal volume (Figure 1).

After the system had stabilized, the pressure and flow signals were recorded for 90 s. After the acquisition, a mean of all the respiratory cycles was calculated. The signals were digitalized and processed using data acquisition software (Lab-View Software, National Instruments, Austin, TX, USA) for later analysis.

In order to adapt and optimize the ventilator when delivering CPAP, the following steps were taken: the nebulizer was removed (although no difference in flow was observed); the expiratory time was set to the minimum; the inspiratory flow was set to the maximum; the room air inlet was opened and the filter removed, thereby allowing maximum flow; the proximal pressure portion of the circuit was closed; and the expiratory valve was removed (Figure 2). The efficiency of the model was tested at CPAP levels of 5, 10 and 15 cmH_2O. The Bird Mark 7 was connected to the hospital oxygen system through a back pressure valve (700810; Moriya, Sao Paulo, Brazil) set to 400 or 500 kPa. At each supply pressure level (400 and 500 kPa) the air flow exiting the Bird Mark 7 was measured with a calibration analyzer (RespiCal-Timeter; Allied Health Care, St. Louis, MO, USA). The oxygen supply pressure was set to 400 or 500 kPA, since supply

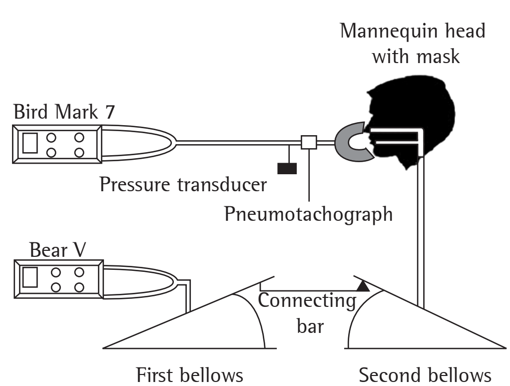

Figure 1 - Illustration of the experimental model with the Bird Mark 7 and the Bear V (mechanical ventilator used to simulate the inspiratory pressure). The first and second bellows constitute the simulator of the respiratory system.

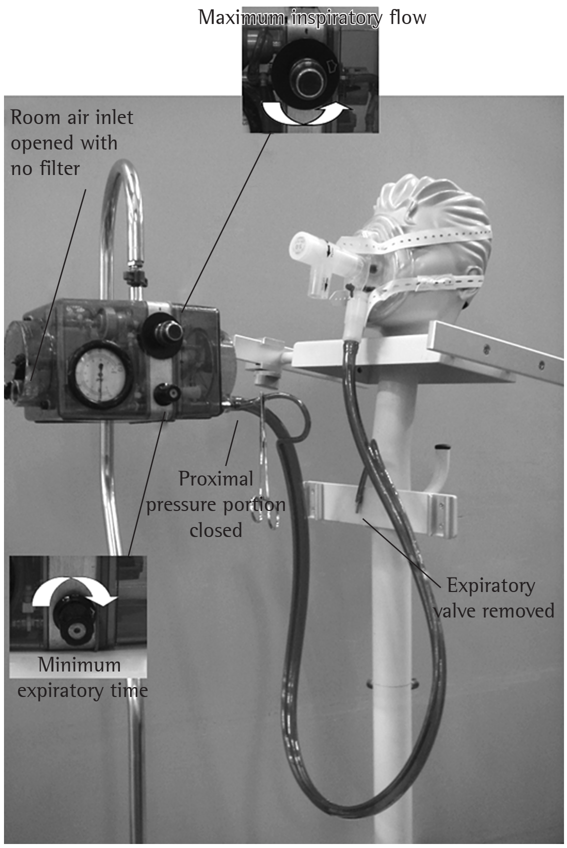

Figure 2 - Bird Mark 7 adapted to offer continuous positive airway pressure. The expiratory time (lower) dial was turned clockwise as far as possible. The inspiratory flow (upper) dial was turned counter-clockwise as far as possible. As can be seen, the proximal pressure portion of the circuit was clamped with surgical forceps.

pressures below these levels generated flow rates of less than 100 L/min, which are insufficient for the CPAP mode.[10]

The efficiency of the adaptation was confirmed by the analysis of three variables:

- the difference between the preset CPAP (5, 10 or 15 cmH_2O) and the pressure measured at the end of the expiration (trueCPAP);
- the area of airway pressure below the CPAP employed ($AREA_{CPAP}$), defined as the area under the level of CPAP from the beginning to the end of the inspiratory flow; and
- the tidal volume generated obtained integrating the flow signal to time.

Ideally, the $AREA_{CPAP}$ should be zero, since the pressure level employed must be constant in order to offer the best treatment.[11] The analysis of the $AREA_{CPAP}$ correlates with the drop in the preset CPAP, but is more relevant to the analysis of the efficiency because it takes into account the drop in the preset CPAP as well as the amount of time that the CPAP was below the preset level during inspiration. At each CPAP level, two different levels of inspiratory pressures were analyzed. They were obtained with different adjustments of the triggering ventilator. The inspiratory pressures were defined as follows:

- Normal inspiratory pressure: respiratory rate of 10 breaths/min, ventilation volume adjusted to 360 mL, peak sinusoidal inspiratory flow rate at 30 L/min and inspiratory time of 1 s; and
- High inspiratory pressure: respiratory rate of 20 breaths/min, ventilation volume adjusted to 650 mL, peak sinusoidal inspiratory flow rate at 60 L/min and inspiratory time of 1 s.

As expected for a mechanical model,[10] the flow and volume values in each respiratory cycle were stable. Therefore, considering that the variance of the obtained data is insignificant, no statistical method other than direct comparison was used.

Results

The rate of continuous air flow generated by the Bird Mark 7 was 99 L/min at a supply pressure of 400 kPa and 110 L/min at a supply pressure of 500 kPa.

Regardless of the ventilator supply pressure (400 or 500 kPa) and inspiratory pressure, the Bird Mark 7 managed to achieve the preset CPAP (trueCPAP) levels of 5 and 10 cmH_2O. However, a CPAP of 15 cmH_2O was not achieved in any of the experimented scenarios (Figure 3).

The CPAP level always dropped during inspiration, regardless of the ventilator supply pressure, the inspiratory pressure and the CPAP level employed. As expected, this decrease was more significant at the high inspiratory pressure (Table 1). The $AREA_{CPAP}$ in relation to CPAP levels of 5 and 10 cmH_2O revealed a small area of airway pressure decrease during inspiration, with a value near zero (Figure 4), which indicates good efficiency. However, the value of the $AREA_{CPAP}$ in relation to a CPAP level of 15 cmH_2O was high (up to 5 cmH_2O/s), indicating unsatisfactory performance of the adapted Bird Mark 7 in delivering a CPAP of 15 cmH_2O.

Regardless of the ventilator supply pressure (400 or 500 kPa), CPAP level and inspiratory pressure, the tidal volume generated by the Bird Mark 7 was quite comparable to that expected for the inspiratory pressure (360 mL in low inspiratory pressure and 650 mL in high inspiratory pressure - Table 1).

Discussion

The Bird Mark 7 adapted to offer NIV in CPAP mode managed to achieve the expected tidal volume in all of the scenarios of inspiratory pressure (normal or high), ventilator supply pressure (400 or 500 kPa) and CPAP (5, 10 or 15 cmH_2O). At the 5 and 10 cmH_2O CPAP levels, the trueCPAP was quite near the preset CPAP, and the $AREA_{CPAP}$ value was near zero. At the 15 cmH_2O CPAP level, the trueCPAP value was under the preset CPAP, and the $AREA_{CPAP}$ value was high.

The Bird Mark 7 adaptation proved efficient in offering CPAP levels of 5 and 10 cmH_2O. However, a worse performance of the adaptation was observed when the Bird Mark 7 was adjusted to offer a CPAP level of 15 cmH_2O. As for the ventilator supply pressure of 400 kPa, mainly at high inspiratory pressure, the performance was very unsatisfactory. However, for the ventilator supply pressure of 500 kPa, the flaws were fewer and yet significant. As the $AREA_{CPAP}$ basically depends on sufficient or insufficient gas supply in relation to the quantity of flow necessary during inspiration,[12] the determining factor of the unsatisfactory performance which occurred in study of the CPAP of 15 cmH_2O was that the flow was insufficient to maintain this pressure. In a previous study, our group showed that, in order to maintain a pressure of 15 cmH_2O, microprocessor-controlled ventilators specific for NIV provide flow rates between 130 and 154 L/min, well above the 99-110 L/min provided by the Bird Mark 7.[10]

The trueCPAP for the CPAP levels of 5 and 10 cmH_2O was equal to the preset value. Again, in tests in which the CPAP was 15 cmH_2O, the adaptation was unsatisfactory. The minor improvement in the performance to reach the preset pressure with high inspiratory pressure is probably related to the greater inspiratory volume generated and the

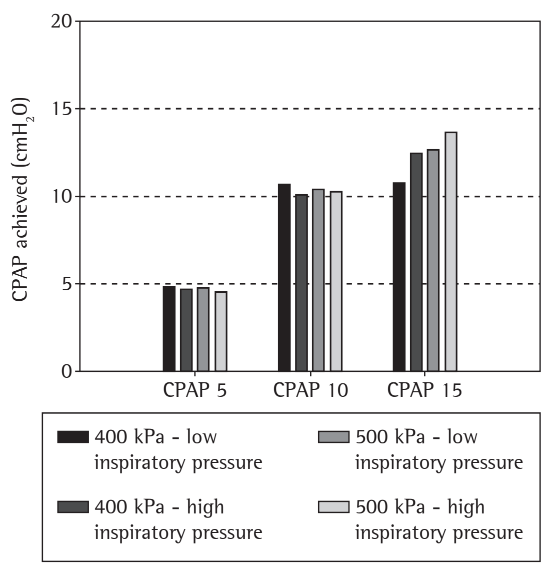

Figure 3 - Difference between the preset continuous positive airway pressure (CPAP; 5, 10 or 15 cmH_2O) and the true end-expiratory pressure.

Table 1 - Tidal volumes and lowest value of continuous positive airway pressure achieved at supply pressures of 400 and 500 kPa.

	V_t (mL)	Lowest CPAP achieved (cmH_2O)	V_t (mL)	Lowest CPAP achieved (cmH_2O)
	400 kPA		500 kPA	
CPAP 5 cmH_2O				
Normal IP	372	4.19	367	4.13
High IP	600	3.74	618	3.63
CPAP 10 cmH_2O				
Normal IP	349	9.74	371	9.63
High IP	635	7.53	642	8.22
CPAP 15 cmH_2O				
Normal IP	355	9.36	382	12.34
High IP	646	8.02	655	10.13

V_t: tidal volume; CPAP: continuous positive airway pressure; and IP: inspiratory pressure.

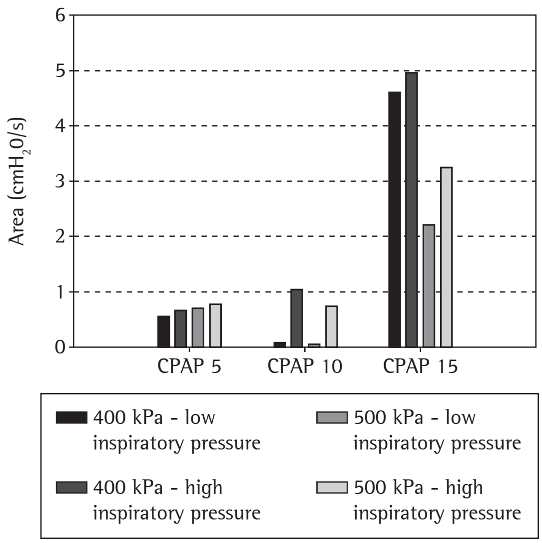

Figure 4 - Airway pressure area below the level of continuous positive airway pressure (CPAP) employed, obtained at the different levels of supply pressure and inspiratory pressure.

consequent greater expiratory volume, which might have allowed greater recovery of the pressure after the drop during inspiration.

In our study, the tidal volume observed was near the preset levels (360 and 650 mL for normal and high inspiratory pressure, respectively), because the Bird Mark 7 delivered a flow that exceeded the inspiratory flow and the demand for volume.

In a previous study, we compared the performance of two continuous flow generators with that of a specific microprocessor-controlled ventilator for NIV in delivering NIV in CPAP mode.[10] In the present study, the Bird Mark 7 performed as well or better than did the flow generators previously evaluated. The $AREA_{CPAP}$ of the adaptation was similar to that of the flow generators and to that of the microprocessor-controlled device at low inspiratory pressures and better than that of the flow generators at high inspiratory pressures.The capacity of the Bird Mark 7 adaptation to reach the preset CPAP value was similar to that of the continuous flow generators. The probable explanation for these similarities between the Bird Mark 7 adaptation and the specific flow generators can also be found in our previous study,[10] in which we showed that continuous flow generators perform best at flow rates of 100 to 120 L/min, comparable to the values obtained with our adaptation of the Bird Mark 7.

The present study showed how to adapt the Bird Mark 7 to offer NIV, as well as demonstrating the efficiency of the adaptation. The relevance of this demonstration is in the capacity to offer NIV in CPAP mode in hospitals where this piece of equipment is the only one available or where there is insufficient equipment for NIV. Unfortunately, we believe this is the situation in Brazil. The capacity to offer NIV is very important, since this is the ventilation modality that has proved efficient in reducing the number of tracheal intubations, as well as in lowering costs, morbidity rates and mortality rates.[1-4]

One limitation of the present study is that it was conducted using a mechanical model of the respiratory system, which, although simulating a clinical situation, does not encompass all of its various and complex aspects. In our model, the mask was well-sealed, with just a small leak, as it is desirable in ideal NIV. However, in a clinic situation in which the seal is inadequate and larger leaks take place, the method of adapting the Bird Mark 7 might be different. These limitations should be overcome in studies involving patients or healthy volunteers.

In conclusion, the efficiency of the Bird Mark 7 adaptation in offering NIV in CPAP mode was good at CPAP values of 5 and 10 cmH_2O and insufficient at a CPAP of 15 cmH_2O. If adapted as in our study, the Bird Mark 7 might be an option for offering CPAP up to 10 cmH_2O in areas where little or no equipment is available.

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