Original Article

Alterations in peak inspiratory pressure and tidal volume delivered by manually operated self-inflating resuscitation bags as a function of the oxygen supply rate*

Alterações da pressão de pico inspiratório e do volume corrente fornecidos por reanimadores manuais com balão auto-inflável em função do fluxo de entrada de oxigênio utilizado

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Abstract

Objective: To assess possible alterations in the tidal volume and peak inspiratory pressure delivered by seven models of manually operated self-inflating resuscitation bags as a function of the oxygen supply rate used. **Methods:** The resuscitation bags tested were the following: Oxigel, models A and B; CE Reanimadores; ProtecSolutions; Missouri; Axmed; and Narcosul. For the measurements, a wall oxygen flow meter, a flow meter/respirometer, a resuscitation bag, a sensor (Tracer 5 unit), and a test lung were connected. In addition, the Tracer 5 unit was connected to a notebook computer. Oxygen supply rates of 1, 5, 10, and 15 L/min were used. **Results:** The tidal volume delivered by the Oxigel model A resuscitation bag when receiving oxygen at a rate of 15 L/min was approximately 99% greater than that delivered when receiving oxygen at a rate of 1 L/min. Similarly, peak inspiratory pressure was approximately 155% greater. Under the same conditions, the tidal volume delivered by the Narcosul resuscitation bag was 48% greater, and peak inspiratory pressure was 105% greater. The remaining resuscitation bags tested showed no significant alterations in the tidal volume or peak inspiratory pressure delivered. **Conclusions:** Under the resistance and compliance conditions used, the resuscitation bags in which the oxygen inflow is directed to the interior of the bag had the patient valve stuck at the inspiratory position when receiving oxygen at a rate ≥ 5 L/min, significantly increasing the tidal volume and peak inspiratory pressure delivered. This did not occur with the resuscitation bags in which the oxygen inflow is directed to the exterior of the bag.

Keywords: Oxygen/administration & dosage; Resuscitation; Equipment and supplies; Pulmonary ventilation; Intensive care.

Resumo

Objetivo: Determinar possíveis alterações do volume corrente e da pressão de pico inspiratório fornecidos por sete modelos de reanimador manual com balão auto-inflável em função do fluxo de entrada de oxigênio utilizado. **Métodos:** Os reanimadores testados foram: Oxigel,modelos A e B; CE Reanimadores; ProtecSolutions; Missouri; Axmed; e Narcosul. Para as aferições, acoplaram-se um fluxômetro de oxigênio de parede, um fluxômetro/respirômetro, um reanimador, um sensor (aparelho Tracer 5) e um pulmão-teste. Além disso, acoplou-se o aparelho Tracer 5 a um *notebook*. Utilizaram-se fluxos de entrada de oxigênio de 1, 5, 10 e 15 L/min. **Resultados:** O volume corrente fornecido pelo reanimador Oxigel modelo A ao receber 15 L/min de oxigênio foi aproximadamente 99% maior que o fornecido ao receber 1 L/min de oxigênio. Da mesma forma, a pressão de pico inspiratório foi 155% maior. Nas mesmas condições, o volume corrente fornecido pelo reanimador Narcosul foi 48% maior, e a pressão de pico inspiratório foi 105% maior. Os demais reanimadores testados não apresentaram alterações significativas do volume corrente e da pressão de pico inspiratório fornecidos. **Conclusões:** Nas condições de resistência e complacência utilizadas, os reanimadores em que o fluxo de entrada de oxigênio é direcionado diretamente ao interior do balão tiveram a válvula do paciente presa em posição de inspiração ao receberem um fluxo ≥ 5 L/min, aumentando significativamente o volume corrente e a pressão de pico inspiratório fornecidos. Isso não ocorreu nos reanimadores em que o fluxo de entrada de oxigênio é direcionado ao exterior do balão.

Descritores: Oxigênio/administração & dosagem; Ressuscitação; Equipamentos e provisões; Ventilação pulmonar; Cuidados intensivos.

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Introduction

Manually operated self-inflating resuscitation bags are devices used to provide positive pressure ventilation to patients who require ventilatory support.[1-3]

These resuscitation bags can be divided into two principal parts: the patient connector and the bag (compressible unit), and, in the latter, in some models, there is a socket to which an oxygen reservoir can be connected (Figure 1). The bag is the part that is compressed by the operator in order to determine the volume to be injected into the respiratory system of patients. The patient connector, to which the resuscitation mask or the endotracheal tube can be connected, is located on the front of the bag. Within the patient connector, there is a directional air valve, designated the patient valve, and, in some models, there is a pressure-limiting valve.

In order to make use of a manually operated self-inflating resuscitation bag work, the operator compresses the bag, creating supra-atmospheric pressure, and this causes the patient valve to obstruct the patient connector outlet, directing the airflow to the respiratory system. Concomitantly, the air-inlet valve closes, preventing the outflow of air from the front of the resuscitation bag. When the operator decompresses the bag, the bag reexpands, creating subatmospheric pressure, and this causes the air-inlet valve to open and take in room air and/or oxygen coming from the oxygen inlet or air from within the oxygen reservoir, when there is one connected to the bag. The patient valve retrocedes, in synchrony, until hitting a spacer, thus allowing the air injected into the respiratory system to be exhaled.

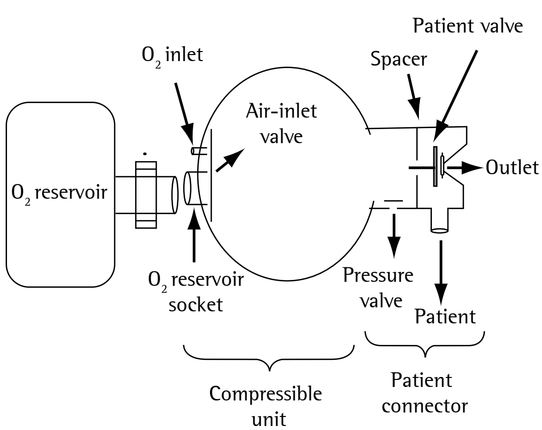

Figure 1 - Schematic representation of the components of a manually operated self-inflating resuscitation bag.

Given the fact that different models can present different functional performances,[1-7] and considering that we found no publications evaluating the performance of manually operated self-inflating resuscitation bags for adults manufactured or marketed in Brazil, together with the fact that these resuscitation bags are commonly available and widely used at outpatient and inpatient health facilities, it seemed to us reasonable to evaluate, using a mechanical model, the performance of these resuscitation bags.

The objective of this study was to assess possible alterations in the tidal volumes and peak inspiratory pressures delivered by seven models of manually operated self-inflating resuscitation bags as a function of the oxygen supply rate used.

Methods

Data were collected in the Respiratory Unit of the State University at Campinas *Hospital das Clínicas* between January of 2006 and January of 2007.

A test lung (Vent Aid, TTL-49504; Michigan Instruments, Grand Rapids, MI, USA), a device for measuring respiratory mechanics (Tracer 5; Intermed, São Paulo, Brazil), a wall oxygen flow meter (Becton Dickinson, Franklin Lakes, NJ, USA), a flow meter/respirometer (953; Oxigel, São Paulo, Brazil), and a notebook computer running the Wintracer software, version 3.3beta (Intermed, São Paulo, Brazil) were used.Seven models of manually operated self-inflating resuscitation bags were tested: Oxigel model A; Oxigel model B; CE Reanimadores (São Paulo, Brazil); ProtecSolutions (Wellington, New Zealand); Missouri (Embu, Brazil); Axmed (São Paulo, Brazil); and Narcosul (Porto Alegre).

As shown in Figure 2, the resuscitation bags tested presented the following characteristics regarding the direction of the oxygen inflow into the bag: parallel to the air-inlet valve—ProtecSolutions; perpendicular to the air-inlet valve—CE Reanimadores, Missouri, Oxigel model B, and Axmed; and directed to the interior of the bag—Oxigel model A and Narcosul.

The test consisted in connecting the wall oxygen flow meter to the flow meter/respirometer, which was connected to the manually operated self-inflating resuscitation bag, which was, in turn,

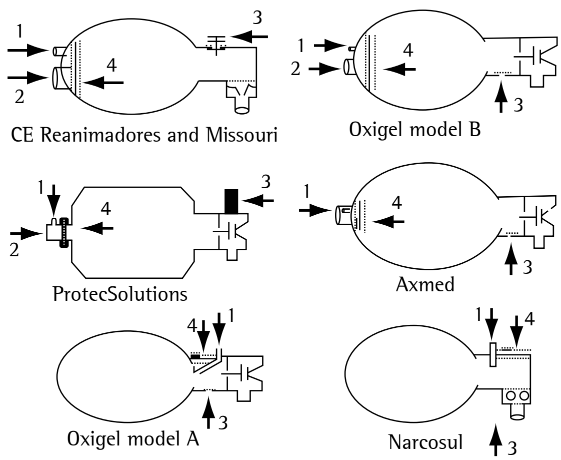

Figure 2 - Schematic representation of seven models of manually operated self-inflating resuscitation bags. 1) oxygen inlet; 2) oxygen reservoir socket; 3) pressure valve; 4) air-inlet valve.

connected to the sensor of the Tracer 5 unit. This sensor was then connected to the test lung, and the Tracer 5 unit was connected to the notebook computer (Figure 3).

For the test lung, compliance was set at 0.05 L/cmH_2O and resistance was set at 20 cmH_2O/L/s. The operator used two-handed compressions to ventilate the test lung for 20 min with each of the resuscitation bags and at each oxygen supply rate, using a respiratory rate of 12 breaths/min. All resuscitation bags were handled by the same person. Oxygen supply rates and respiratory rates were continuously measured by the devices connected to the testing system.

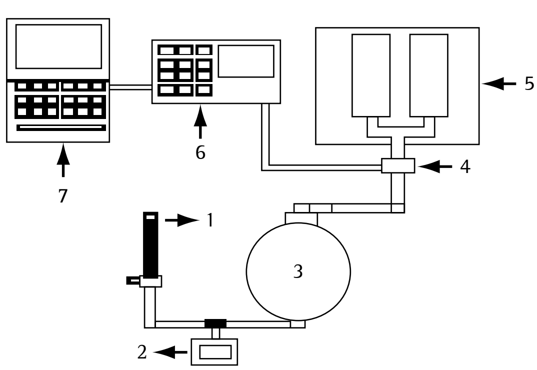

Figure 3 - Schematic representation of the model used to measure the tidal volume and peak inspiratory flow delivered by manually operated self-inflating resuscitation bags: 1) wall oxygen flow meter; 2) flow meter/respirometer; 3) manually operated self-inflating resuscitation bag; 4) sensor (Tracer 5 unit); 5) test lung; 6) Tracer 5 unit; 7) notebook computer.

During the handling of the resuscitation bags, the mobility of the patient valve was checked, and the variables tidal volume and peak inspiratory pressure values recorded by the Tracer 5 unit were transferred to the notebook computer. The means and standard deviations were calculated using the BioEstat 3.0 and the Excel XP programs. Analysis of variance was used.

Results

Table 1 shows the means and standard deviations for the tidal volumes and peak inspiratory pressures delivered by each of the seven models of manually operated self-inflating resuscitation bags when receiving oxygen at rates of 1, 5, 10, and 15 L/min.

The tidal volume delivered by the Oxigel model A resuscitation bag when receiving oxygen at a rate of 15 L/min was approximately 99% greater than that delivered when receiving oxygen at a rate of 1 L/min. Under the same conditions, the tidal volume delivered by the Narcosul resuscitation bag was approximately 48% greater (Table 1).

The peak inspiratory pressure delivered by the Oxigel model A resuscitation bag when receiving oxygen at a rate of 15 L/min was approximately 155% greater than that delivered when receiving oxygen at a rate of 1 L/min. Under the same circumstances, the peak inspiratory pressure delivered by the Narcosul resuscitation bag was approximately 105% greater (Table 1).

Figure 4 shows the alterations in the peak inspiratory pressure delivered by the manually operated self-inflating resuscitation bags as a function of the oxygen supply rates of 1 and 15 L/min during the respiratory cycle. The peak inspiratory pressure delivered by the Oxigel model A and the Narcosul resuscitation bags was found to be greater when they were receiving oxygen at a rate of 15 L/min than when they were receiving oxygen at a rate of 1 L/min, and this did not occur with any of the other models tested.

We observed that the Oxigel model A and the Narcosul resuscitation bags had the patient valve stuck at the inspiratory position when receiving

Table 1 – Means and standard deviations of the peak inspiratory pressures and tidal volumes delivered by seven models of manually operated self-inflating resuscitation bags when receiving oxygen at rates of 1, 5, 10, and 15 L/min.

Variable	O_2 (L/min)	Manually operated self-inflating resuscitation bag						
		Oxigel model A	Oxigel model B	Missouri	ProtecSolutions	CE Reanimadores	Axmed	Narcosul
Peak inspiratory pressure (cmH_2O)	1	16.1 ± 0.3	18.5 ± 0.5	17.0 ± 0.2	15.4 ± 0.3	19.8 ± 0.1	20.1 ± 0.2	16.4 ± 0.5
	5	31.6 ± 0.5	17.8 ± 0.7	17.4 ± 0.3	14.7 ± 0.4	18.5 ± 0.1	20.2 ± 0.2	24.1 ± 0.6
	10	36.4 ± 0.4	18.3 ± 0.8	17.5 ± 1.2	15.8 ± 0.7	18.1 ± 0.1	19.5 ± 0.2	25.2 ± 0.3
	15	41.0 ± 0.8	17.5 ± 0.5	17.1 ± 0.2	15.5 ± 0.3	18.1 ± 0.1	19.8 ± 0.2	33.6 ± 0.6
	p	< 0.05	NS	NS	NS	NS	NS	< 0.05
Tidal volume (mL)	1	770.8 ± 0.4	834.4 ± 0.5	808.4 ± 0.9	738.1 ± 1.8	710.4 ± 1.8	798.4 ± 0.2	782.1 ± 0.2
	5	847.0 ± 0.4	837.1 ± 0.4	808.4 ± 1.0	737.4 ± 1.4	716.5 ± 1.0	797.1 ± 0.2	898.1 ± 0.7
	10	1.416.6 ± 0.4	829.3 ± 1.5	802.5 ± 0.2	750.8 ± 0.8	715.1 ± 0.4	796.5 ± 0.2	1.011.2 ± 0.3
	15	1.532.6 ± 0.4	847.5 ± 0.5	805.1 ± 0.2	730.5 ± 0.3	713.1 ± 0.1	797.8 ± 0.2	1.147.6 ± 0.6
	p	< 0.05	NS	NS	NS	NS	NS	< 0.05
Inspiratory flow (L/min)	1	87.8 ± 0.4	94.4 ± 0.5	95.2 ± 0.9	85.1 ± 1.8	100.4 ± 1.8	106.4 ± 0.2	92.1 ± 0.5
	5	89.6 ± 0.4	95.3 ± 1.5	94.2 ± 0.2	84.8 ± 0.8	98.1 ± 0.4	105.5 ± 0.2	110.1 ± 0.6
	10	96.6 ± 0.4	95.3 ± 1.5	93.5 ± 0.2	85.8 ± 0.8	99.1 ± 0.4	102.5 ± 0.2	110.2 ± 0.3
	15	98.6 ± 0.8	95.5 ± 0.5	97.1 ± 0.2	87.5 ± 0.3	98.1 ± 0.1	103.8 ± 0.2	114.6 ± 0.6
	p	< 0.05	NS	NS	NS	NS	NS	< 0.05

NS: not significant.

oxygen at a rate ≥ 5 L/min, and this was not detected in any of the other models tested.

Discussion

The increase in tidal volume and peak inspiratory pressure during ventilation with a manually operated self-inflating resuscitation bag can cause complications such as barotraumas,[8,9] pneumothorax,[10,11] gastric/esophageal dilatation or rupture with the formation pneumoperitoneum,[12] and aspiration of gastric content.[13] These complications, when accompanied by certain clinical situations, are potentially fatal.[9]

It was visually confirmed that the manually operated self-inflating resuscitation bags in which the oxygen inflow is directed to the interior of the bag (Oxigel model A and Narcosul) had the patient valve stuck at the inspiratory position when receiving oxygen at a rate of ≥ 5 L/min. This occurred with these models due to the fact that the oxygen inflow is directed to the interior of the bag, increasing the intra-bag pressure and making the patient valve stick at the inspiratory position. Therefore, the oxygen inflow is directed to the interior of the test lung, leading to the increase in tidal volume and peak inspiratory pressure.

Our results show that, when receiving oxygen at a rate of 15 L/min, the Oxigel model A resuscitation bag continued to deliver oxygen to the test lung after the expiratory phase, consequently delivering gas volume from the end of expiration to the beginning of the next compression of the bag, causing an increase in the peak inspiratory pressure and tidal volume delivered to the test lung. Although it was possible to ventilate the test lung under these conditions, the outflow of air was diverted from the patient connector air outlet to the pressure valve (Figure 2). When the bag was not compressed, the pressure within the resuscitation bag/test lung system increased to 40 cmH_2O, the level at which the pressure valve opens.

The manually operated self-inflating resuscitation bags in which the oxygen inflow is directed to the exterior of the bag (Oxigel model B, Missouri, CE Reanimadores, ProtecSolutions, and Axmed) presented no alterations in the tidal volume and peak inspiratory pressure delivered as a function of the oxygen supply rate used, since the oxygen inflow used is not directed to the interior of the bag and, therefore, does not affect the performance of the patient valve.

Since there can be variations in the performance of manually operated self-inflated resuscitation bags as a function of the oxygen supply rate used, physicians, nurses, and physical therapists should

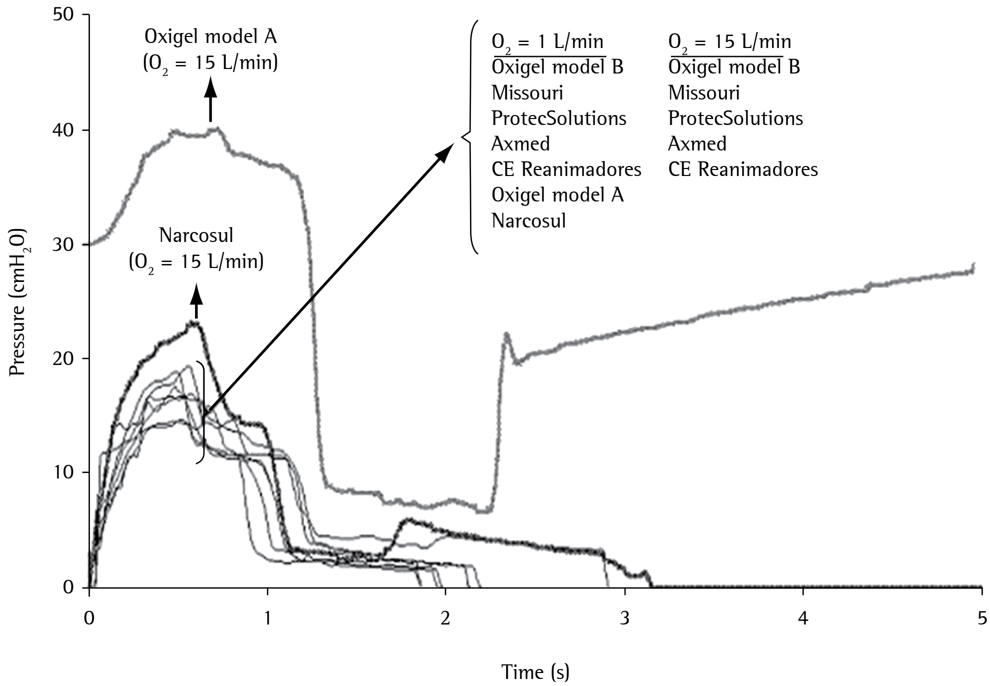

Figure 4 - Alterations in the peak inspiratory pressure delivered by seven models of manually operated self-inflating resuscitation bags as a function of the oxygen supply rate used (1 and 15 L/min).

adjust this supply rate so that the equipment can function without posing any risks to the patient.

During the test, the respiratory rate used in each resuscitation bag was 12 breaths/min, and the operator used two-handed compression, since this is the protocol commonly used for ventilation with a resuscitation bag.[8,9,11,14]

Under the resistance and compliance conditions used, the resuscitation bags in which the oxygen inflow is directed to the interior of the bag had the patient valve stuck at the inspiratory position when receiving oxygen at a rate ≥ 5 L/min, altering the tidal volume and peak inspiratory pressure delivered. This did not occur with the resuscitation bags in which the oxygen inflow is directed to the exterior of the bag.

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