The Changes in Delivered Oxygen Fractions Using Laerdal Resuscitator Bag with Different Types of Reservoir

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One of the disadvantages of the Laerdal resuscitator bag is that it does not deliver a high concentration of oxygen without a reservoir and an appropriate technique of ventilation. With a specific device that is able to compress a resuscitator bag mechanically at a regular volume, ventilator rate, and speed, we evaluated the effects of various factors (the tidal volume, the ventilator rate, the oxygen flow rate, the type of reservoir) of the Laerdal resuscitator bag during positive pressure ventilation that affect the delivered oxygen fraction ($F_{2O_2}$) and also whether 250 mL and 500 mL corrugated tubes could be used as substitutes for the reservoir bag. The 250 mL corrugated tube increased the $F_{2O_2}$ to over 96% with an oxygen flow rate of 15 L/min. The 500 mL corrugated tube increased the $F_{2O_2}$ to over 96% with an oxygen flow rate of 10 L/min regardless of the ventilator rate at a fixed tidal volume of 500 mL. At the identical fixed tidal volume of 500 mL, the 1600 mL reservoir bag increased the $F_{2O_2}$ to over 92% with an oxygen flow rate of 5 L/min and to over 96% at 7.5 L/min regardless of the ventilator rate. We concluded that the $F_{2O_2}$ of the Laerdal resuscitator bag depends on various factors such as tidal volume, ventilator rate, oxygen flow rate, and type of reservoir and both the 250 mL and 500 mL corrugated tubes can be used as substitutes.

Key Words: Oxygen fractions, Laerdal resuscitator bag, reservoir, corrugated tube

INTRODUCTION

In the emergency room or intensive care unit, a high oxygen fraction is often required during positive pressure ventilation with a resuscitator bag to prevent hypoxia and increase tissue oxygenation during cardiopulmonary failure. The currently used resuscitator bags can not deliver a high enough oxygen fraction without a reservoir or specific technique during positive pressure ventilation. The variables affecting the oxygen fraction are the presence of a reservoir, the ventilator rate and the refilling time of the bag. There are some studies reported on the delivered oxygen fraction ($F_{2O_2}$) but they were mainly based on the tests of ventilating lung manually. Therefore, a specific device which enables a resuscitator bag to be compressed mechanically at regular intervals was designed and the $F_{2O_2}$ of the Laerdal resuscitator bag was measured according to the changes in tidal volume, ventilator rate, and minute volume. This study was performed with and without reservoir bag, and with corrugated tubes.

One of the main objectives of this study was to evaluate the effects of various factors (the tidal volume, the ventilator rate, the oxygen flow rate, the type of reservoir) of the Laerdal resuscitator bag during positive pressure ventilation that affect the $F_{2O_2}$. Another objective was to determine whether 250 mL and 500 mL corrugated tubes could be used as substitutes for the reservoir bag.

MATERIALS AND METHODS

A Laerdal resuscitator bag (Laerdal silicone resuscitators®, Laerdal Co., Stavanger, Norway) airtight in a wooden box, which can also be connected to an anesthetic machine ventilator (Dameca DK 2610, Copenhagen, Denmark). The non-rebreathing valve, intake valve and the nipple for the Laerdal resuscitator bag oxygen tubing were exposed. An oxygen analyzer (Puritan Bennett 7820 oxygen monitor, PB, CA, USA) and a spirometer (Boehringer, Ingelheim, CT, USA)
was attached between the non-rebreathing patient valve and the test lung (DLL, Michigan Instruments, Grand Rapids, MI, USA). The nipple for oxygen tubing was connected to the wall oxygen source. For regular compression of the self-refilling ventilation bag, the sealed wooden box was connected to the bellows of the anesthetic machine ventilator (Fig. 1, and 2) and the inspiration-expiration ratio was fixed at 1:2.

To observe the effects of each of the variables affecting the $F_{O_2}$, the corresponding $F_{O_2}$ was measured whilst altering each of the variables (tidal volume, ventilation rate per minute, minute volume, oxygen flow rate, 1600 ml reservoir bag, 250 ml and 500 ml corrugated tubes). Prior to each $F_{O_2}$ measurement the oxygen analyzer was calibrated at room air for 5 minutes. When the $F_{O_2}$ reached a plateau at each supplemental oxygen flow rates, the corresponding $F_{O_2}$ was measured.

**RESULTS**

The corresponding $F_{O_2}$ according to the changes of the tidal volume and the ventilator rate at a fixed minute volume (5000 ml) (Fig. 3)

Without a reservoir bag or a corrugated tube, the $F_{O_2}$s measured were 45%, 55%, 60%, 65% and 69% at oxygen flow rates of 5 L/min, 7.5 L/min, 10 L/min, 12.5 L/min and 15 L/min respectively. When using a 250 ml corrugated tube, the corresponding $F_{O_2}$s were 89%, 95%, 96% and over 96% with oxygen flow rates the same as above. With a 500 ml corrugated tube, the corresponding $F_{O_2}$s measured were 91%, 96% and over 96% at oxygen flow rates of 5 L/min, 7.5 L/min and over 10 L/min respectively. When a reservoir bag was used, the $F_{O_2}$s measured were over 92% and over 96% at oxygen flow rates of 5 L/min and over 7.5 L/min respectively.

The $F_{O_2}$ as a function of the ventilator rate at a fixed tidal volume (500 ml) (Fig. 4)

Without a reservoir bag or a corrugated tube, the $F_{O_2}$ progressively decreased as the ventilator rate was increased. As the oxygen flow rate was increased, the $F_{O_2}$ progressively increased. However, even though the oxygen flow rate was increased to 15 L/min the corresponding $F_{O_2}$

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**Fig. 1.** The Laerdal resuscitator bag (A) and the sealed wooden box which encompasses the Laerdal resuscitator bag connected to a test lung, a spirometer and an oxygen analyzer (B).

**Fig. 2.** Schematic drawing of the sealed wooden box with its connection to a test lung, a spirometer, an oxygen analyzer and a bellow of an anesthetic machine ventilator.
was only 69% at a ventilator rate of 10/min. When a 250 mL corrugated tube with an oxygen flow rate of 5 L/min was used, the measured F$_{t}$O$_{2}$s were 78%, 68% and 63% at ventilator rates of 10/min, 15/min and 20/min, respectively. At an oxygen flow rate of 15 L/min, the F$_{t}$O$_{2}$ increased to over 96% regardless of the ventilator rate. When a 500 mL corrugated tube with an oxygen flow rate of 5 L/min was used, the F$_{t}$O$_{2}$s measured were 90%, 69% and 65% at ventilator rates of 10/min, 15/min and 20/min respectively. The F$_{t}$O$_{2}$ increased to over 96% when an oxygen flow rate of 10 L/min was used, regardless of the ventilator rate. When a reservoir bag was used with an oxygen flow rate of 5 L/min, the F$_{t}$O$_{2}$s were 93%, 77% and 69% at ventilator rates of 10/min, 15/min and 20/min respectively. The F$_{t}$O$_{2}$ increased to over 96% when the oxygen flow rate was more than 7.5 L/min, regardless of the ventilator rate.

The corresponding F$_{t}$O$_{2}$ according to the changes of the tidal volume at a fixed ventilator rate (10/min) (Fig. 5)

Without a reservoir bag or a corrugated tube, the F$_{t}$O$_{2}$ progressively decreased as the tidal volume increased, and as the oxygen flow rate was increased, the F$_{t}$O$_{2}$ progressively increased. However at a tidal volume of 250 mL even when the oxygen flow rate was 15 L/min, the F$_{t}$O$_{2}$ was only 74%. When a 250 mL corrugated tube was used at an oxygen flow rate of 5 L/min, the measured F$_{t}$O$_{2}$s were 95%, 78% and 55% at tidal volumes of 250 mL, 500 mL and 600 mL respectively. When the oxygen flow rate was increased to 15 L/min, the measured F$_{t}$O$_{2}$s were 99%, 97% and 86% at the same tidal volumes as above. When a 500 mL corrugated tube was used, the corresponding F$_{t}$O$_{2}$s were 96%, 89% and 83% at an oxygen flow rate of 5 L/min and 99%, 98% and
92% at an oxygen flow rate of 15 L/min. When using a reservoir bag, the corresponding FIO2s measured were 95%, 93% and 79% with an oxygen flow rate of 5 L/min. When the oxygen flow rate was increased to more than 7.5 L/min, the FIO2 increased to over 96% regardless of the tidal volume.

**DISCUSSION**

There are many types of resuscitator bags (the PMR II, the Intertest, the Pedi-Blue, the MPR, the LSP, the CPR, the Pulmonex, the Ambu, the Laerdal Resuscit 2, the Hope 2, the Airbird etc.) according to the manufacturers. Although several studies have been carried out to demonstrate the characteristics of various types of resuscitator bags and FIO2s, most of them were performed with positive pressure ventilation by manual compression. Because the accuracy of the FIO2s reported for resuscitator bags during positive pressure ventilation by manual compression was questionable, a specific device was designed to achieve regular mechanical compression of the resuscitator bag. With this, the FIO2 of the Laerdal resuscitator bag, which has been widely used since the past, was measured.

Carden et al. showed that at an oxygen flow rate of 15 L/min with a minute volume of 8 L/min the maximum FIO2 of the Laerdal resuscitator with a 250 mL reservoir bag was approximately 70%. Cambell et al. showed that the FIO2 increased from 21% to 41% with an oxygen flow rate of 15 L/min without reservoir, regardless of the ventilator rate. In addition, they showed that attaching a 100 mL corrugated tube increased the FIO2 from 41% to 53% regardless of the ventilator rate. It was shown that increasing the corrugated tube volume to 400 mL increased the FIO2 to 82%. Replacing the corrugated tube with a 2.5 L reservoir bag further increased the FIO2 to 95% even at a ventilator rate of 20/min and to 100% when the ventilator rate was reduced to 12/min. They also showed that despite using a 2.5 L reservoir bag, reducing the oxygen flow rate from 15 L/min to 10 L/min caused a significant reduction in FIO2 from 95% to 73% at a ventilator rate of 20/min. However, no change was observed when a ventilator rate of 12/min was used. Hence, they recommended that a 2.5 L bag with an oxygen flow rate of 15 L/min be used as the reservoir for the Laerdal resuscitator bag and not the corrugated tubes.

In our study, the 250 mL corrugated tube increased the FIO2 to over 96% when the oxygen flow rate was 15 L/min and the 500 mL corrugated tube increased the FIO2 to over 96% when the oxygen flow rate was 10 L/min. This was regardless of the ventilator rate at a fixed tidal volume of 500 mL. The 1600 mL reservoir bag increased the FIO2 to over 92% when the oxygen flow rate was 5 L/min and to over 96% when the oxygen flow rate was 7.5 L/min at a fixed tidal volume of 500 mL regardless of the ventilator rate.

To provide adequate positive pressure ventilation in adults, a tidal volume of 10-15 mL/kg and a ventilator rate of 10-12/min is necessary and a ventilator rate of 20/min in children and infants.
Furthermore based upon our results, It is proposed that except in patients requiring hyperventilation, the 250mL and 500mL corrugated tubes can be used as substitutes for the reservoir bag. Moreover, If high oxygen flow rates can be supplied, the F\textsubscript{2}O\textsubscript{2} can be increased more rapidly.

In conclusion, the F\textsubscript{2}O\textsubscript{2} of the Laerdal resuscitator bag was shown to depend on various factors: the tidal volume, the ventilator rate, the oxygen flow rate, the types of reservoir. On the basis of these results with appropriate oxygen flow rates, both 250mL and 500mL corrugated tubes can be used as substitutes for the reservoir bag.

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