The Journal of Emergency Medicine, Vol 11, pp 685–689, 1993

Original Contributions

INFLUENCE OF TIDAL VOLUME, RESPIRATORY RATE, AND SUPPLEMENTAL OXYGEN FLOW ON DELIVERED OXYGEN FRACTION USING A MOUTH TO MASK VENTILATION DEVICE

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☐ **Abstract—We examined the influence of the following parameters in determining the FiO_2 delivered to a pediatric lung model using the mouth-to-mask method of resuscitation: rate of ventilation, inspiratory tidal volumes, and supplemental oxygen flow. With a ventilator rate of 20/min and tidal volumes (V_t) ≤ 100 mL, an FiO_2 of approximately .50 was observed with a supplemental oxygen flow of 5 L/min. Increasing the supplemental oxygen flow to 15 L/m did not appreciably increase the FiO_2 (FiO_2 = .53 versus FiO_2 = .60, respectively), but did cause a significant and unintended increase in V_t. Similar results were noted with a ventilator rate of 12/min and V_t ≤ 100 mL (FiO_2 = .68 versus FiO_2 = .73, respectively). We also observed a potentially hazardous situation involving the positioning of the supplemental oxygen port that might result in high inspiratory pressures (stacking of breaths) to the pediatric patient. We believe additional testing is warranted prior to widespread use of this device in children.**

☐ **Keywords—mouth-to-mask ventilation; pediatrics; cardiopulmonary resuscitation; oxygen**

INTRODUCTION

Studies (1–4) using "trained" medical personnel have detailed the difficulties encountered in single rescuer ventilation using the bag–valve–mask technique. Although the bag–valve–mask delivers a greater FiO_2 than mouth-to-mask, these studies indicate that a significantly smaller tidal volume (509 mL) is delivered by "inexperienced" personnel when compared to endotracheal intubation (1193 mL) and mouth-to-mask ventilation (1093 mL) (3).

The etiology of cardiorespiratory arrest in adults is most often a cardiac dysrhythmia. In children, cardiorespiratory arrest most often results from hypoxia secondary to apnea or respiratory failure. In both instances assisted manual resuscitation by mouth-to-mouth, bag–valve–mask, or mouth-to-mask is recommended until the return of spontaneous respiration or until a more permanent form of airway management (that is, endotracheal intubation) can be established (5).

Mouth-to-mouth resuscitation is a method of resuscitation that does not allow for supplemental oxygen administration. The FiO_2 administered by this route is approximately 16%. For the pediatric patient who has arrested because of hypoxia, this FiO_2 may not be sufficient.

A perceived risk of infection when performing mouth-to-mouth resuscitation on unknown victims has developed among health care employees even though transmission of the human immunodeficiency virus or hepatitis B virus has not been documented (6–7). Because of these concerns, bag–valve–mask or mouth-to-mask ventilation has been recommended when possible. Bag–valve–mask ventilation provides supplemental oxygen delivery and limits direct skin contact with the victim; mouth-to-mask resuscitation has been reported in adult models to de-

RECEIVED: 2 November 1992; FINAL SUBMISSION RECEIVED: 23 April 1993; ACCEPTED: 20 May 1993

0736-4679/93 $6.00 + .00

liver a greater tidal volume than either bag–valve–mask or mouth-to-mouth ventilation when used by both "trained" and "untrained" rescuers (1–2).

Mouth-to-mask resuscitation is a process in which the forced exhalation of the rescuer is delivered through a face mask, which is held firmly over the patient's mouth and nose. Modifications to this device can provide other advantages when compared with mouth-to-mouth resuscitation. These include 1) protective filters and one-way valves that theoretically lessen the incidence of exposure to gastric secretions or infectious agents, and 2) supplemental oxygen adaptors to increase oxygen delivery to the patient. A possible limitation in the use of the mouth-to-mask device has been the inability to deliver supplemental oxygen >80% (6). An FiO_2 from .34 to .81 may be attained with oxygen flows ranging from 2 to 14 L/min depending upon the particular product and subsequent modifications (8).

Although the use of the mouth-to-mask device with large tidal breaths has been reported in adult models (1–2), its use in a pediatric model, requiring smaller tidal breaths, has not been investigated. We examined the influence of the rate of assisted ventilation, tidal volume, and supplemental oxygen flow on the FiO_2 delivered to a pediatric lung model using a mouth-to-mask device.

MATERIALS AND METHODS

The mouth-to-mask device (Intertech Resources, Inc., Bannockburn, IL) in use at our institution consists of a mouth piece, 50-mL corrugated extension tube, respiratory filter, one-way "duckbill" valve, exhaust valve, and a standard resuscitation mask (Figure 1A). This device has been adapted to incorporate a supplemental oxygen delivery port. This port may be inserted either between the mouth piece and the one-way valve (Figure 1B) or between the face mask and the one-way valve (Figure 1C).

A pediatric ventilator (Bird VIP, Bird Product Corporation, Palm Springs, CA) with a standard ventilator circuit (BabyFlex Ventilator Circuit, Baxter Health-Care Corporation, Valencia, CA) was used to simulate rescue breathing and to provide consistent breaths. The humidifier was removed from the circuit to eliminate compressible volume loss. The respiratory pattern was maintained in the volume control mode, with a ventilator flow rate of 20 L/min. Incremental tidal volumes from 50 to 700 mL at both 12 and 20 breaths per minute were examined. Volumes ≥750 mL could not be achieved with this ventilator and were not examined. For each of the above parameters, supplemental oxygen was delivered through the mouth-to-mask device at flow rates of 5 L/min, 10 L/min, or 15 L/min from a Thorp tube connected to a standard wall oxygen outlet. The face mask of this device was removed and a test lung was connected at that location (Life Mode Training Test Lung, Grand Rapids, MI). The compliance of the test lung was 0.05 L/cm H_2O. Tidal volumes delivered through the mouth-to-mask device were verified by serial measurements on the test lung. An oxygen analyzer (Instrumentation Laboratories 408, Lexington, MA) was calibrated to both 21% and 100% (accuracy ± 1%) and was inserted between the test lung and supplemental oxygen port. Mean (±SD) values for high and low FiO_2 for 6 consecutive tidal breaths at each oxygen flow rate, respiratory rate, and tidal volume were recorded.

Data were analyzed using Systat version 5.0 for the Macintosh Computer (Systat Inc., Evanston, IL). Six measurements were obtained for all measurements of FiO_2 and actual tidal volume delivered. All data are presented as the mean and SD of the minimum delivered FiO_2 for a given oxygen flow rate, ventilator rate, and tidal volume. A Mann–Whitney rank sum test was used for the continuous variable comparisons of FiO_2 Delivered between groups (Table 1 and Table 2), and an independent *t* test was used for tidal volumes delivered at tidal volumes of 5, 10, and 15 L of supplemental oxygen (Table 3).

RESULTS

We originally planned to examine the FiO_2 delivered to the test lung with the supplemental oxygen port inserted in two locations: between the mouth piece and the one-way valve (Figure 1B) and between the one-way valve and the face mask (Figure 1C). However, it was observed that passive exhalation was prohibited when the supplemental oxygen port was located above the one-way valve (as depicted in Figure 1B), and supplemental oxygen was delivered. This occurred because supplemental oxygen flow through the one-way valve was sufficient to keep the low resistance one-way valve open and the expiratory valve closed. Because of this observation, the supplemental oxygen port was removed and reinserted between the mask and the one-way valve. All reported values were obtained with the supplemental oxygen port located in this location (Figure 1C).

At a ventilation rate of 20/min, large tidal volumes ($V_t \geq 300$ mL) delivered through the mouth-to-mask device to the lung model resulted in an FiO_2

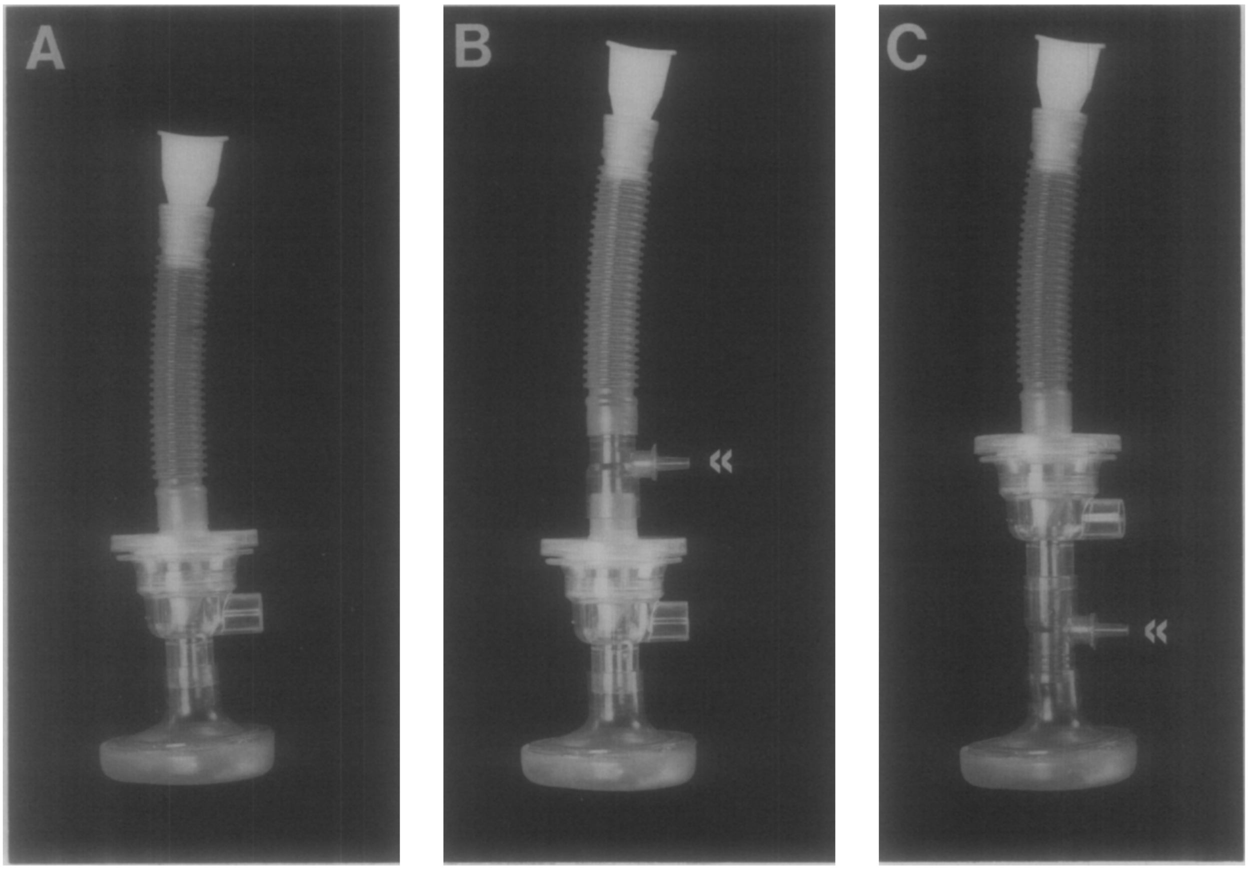

Figure 1. Panel A shows the mouth-to-mask device as supplied by the manufacturer. Panel B shows the device modified with the supplemental oxygen port (arrow) positioned between the mouthpiece and the one-way valve. With the supplemental oxygen port inserted at this location, "stacking of the breaths" occurred. Panel C shows the device with the supplemental oxygen port (arrow) positioned between the facemask and the one-way valve.

from .37 to .52 with supplemental oxygen flow of 5 to 15 L/min. Smaller tidal volumes (≤200 mL) produced an FiO_2 from .42 to .62 with a supplemental oxygen flow of 5 to 15 L/min (Table 1).

A second factor associated with the delivered FiO_2 was the frequency of assisted ventilation. A slower respiratory rate of 12 breaths/min (Table 2) produced an FiO_2 that was 15% to 30% greater at each of the oxygen delivery rates (5, 10, and 15 L/min) than produced with a respiratory rate of 20 breaths/

Table 1. FiO_2 Delivered at a Respiratory Frequency of 20/min

V_t(mL) Delivered	FiO_2 Delivered (×100) with Respiratory Rate = 20		
	5 L/min	10 L/min	15 L/min
50	54.7 ± 0.20	57.3 ± 0.21	61.9 ± 0.36
100	52.7 ± 0.08	55.4 ± 0.17	57.9 ± 0.05
200	42.1 ± 0.27	48.7 ± 0.11	53.7 ± 0.08
300	38.6 ± 0.06	46.4 ± 0.12	51.8 ± 0.00
400	38.4 ± 0.05	46.4 ± 0.06	51.5 ± 0.05
500	38.0 ± 0.00	46.2 ± 0.04	51.6 ± 0.06
600	37.5 ± 0.04	45.9 ± 0.08	51.2 ± 0.06
700	37.0 ± 0.00	45.5 ± 0.04	47.0 ± 0.10

All comparisons of FiO_2 Delivered for the same V_t Delivered and different supplemental oxygen flow rates of groups were statistically significant ($p < 0.005$).

Table 2. FiO_2 Delivered at a Respiratory Frequency of 12/min

V_t (mL) Delivered	FiO_2 Delivered (×100) with Respiratory Rate = 12		
	5 L/min	10 L/min	15 L/min
50	71.2 ± 0.11	74.7 ± 0.16	75.3 ± 0.09
100	65.4 ± 0.23	71.2 ± 0.17	72.0 ± 0.18
200	58.7 ± 0.27	66.4 ± 0.15	69.0 ± 0.06
300	53.1 ± 0.29	63.2 ± 0.10	66.6 ± 0.14
400	49.8 ± 0.41	60.2 ± 0.23	64.1 ± 0.12
500	47.2 ± 0.29	57.5 ± 0.16	61.3 ± 0.11
600	45.5 ± 0.20	55.2 ± 0.08	59.2 ± 0.10
700	44.9 ± 0.33	55.3 ± 0.16	59.5 ± 0.19

All comparisons of FiO_2 Delivered for the same V_t Delivered and different supplemental oxygen flow rates of groups were statistically significant ($p < 0.005$).

min (Table 1). In addition, when maintaining the V_t and assisted ventilation rate constant, increasing the supplemental oxygen delivery rate from 5 L/minute to 15 L/minute increased the delivered FiO_2 by 5% to 15% for smaller tidal breaths (≤200 mL) to 22% in larger tidal breaths (≥300 mL). In no instance did the FiO_2 measured through the mouth-to-mask device exceed 80%.

The addition of supplemental oxygen through the mouth-to-mask device augmented the actual tidal volume delivered to the test lung (Table 3). For smaller tidal volumes (≤200 mL), increasing the supplemental oxygen flow from 5 L/min to 15 L/min significantly increased the actual tidal volume delivered to the lung model from 40% to 230%.

DISCUSSION

Safar (4) previously reported that when artificial ventilation was established via the nasal passages, approximately 30% of patients could not expire because of a flap valve occlusion at the soft palate. We observed a similar circumstance when the supplemental oxygen port was attached above the "duckbill" valve on the mouth-to-mask device. This obstruction in exhalation may result in gastric dilatation, gastric rupture (9), or pneumothorax. Because of the compatibility and standard diameter fittings among respiratory therapy equipment, the supplemental oxygen port may be easily inserted either between the mouth piece and the one-way valve (Figure 1B) or between the face mask and the one-way valve of the mouth-to-mask device (Figure 1C). This problem may also exist in other similar mouth-to-mask devices that incorporate a one-way valve system with a supplemental oxygen port.

Respiratory frequency, supplemental oxygen delivery rate, and V_t all influenced the delivered FiO_2. This was probably the result of dilution of the reservoir of oxygen within the tubing of this device. When the supplemental oxygen flow remained constant, any increase in respiratory frequency or tidal volume resulted in decreased FiO_2 delivered to the lung model. Increasing the supplemental oxygen flow through the mouth-to-mask device resulted in in-

Table 3. Effects of Supplemental Oxygen Flow on the V_t Actual to a Pediatric Lung Model

V_t (mL) Delivered	V_t Actual (5 L/min)	%V_t Change	V_t Actual (10 L/min)	% V_t Change	V_t Actual (15 L/min)	%V_t Change
50	98 ± 4.1	96	117 ± 5.2	134	168 ± 7.5	236
100	157 ± 5.2	57	195 ± 5.5	95	221 ± 7.5	121
200	278 ± 7.5	39	315 ± 5.5	58	405 ± 5.5	103
300	393 ± 5.2	31	485 ± 5.5	62	553 ± 8.2	84
400	501 ± 4.1	25	611 ± 7.5	53	746 ± 24.2	87
500	615 ± 5.5	23	790 ± 6.3	58	910 ± 6.3	82
600	756 ± 18.6	26	916 ± 16.3	53	1096 ± 5.2	83
700	876 ± 5.2	25	1176 ± 5.2	68	1231 ± 24.8	76

V_t Delivered is defined as the volume of gas delivered by the ventilator.
V_t Actual is the total volume measured by serial measurements to the test lung.
All comparisons of V_t Actual (for V_t Delivered) at different oxygen flow rates were statistically significant ($p < 0.005$).

creased delivered FiO_2. At tidal breaths less than 100 mL, increasing the oxygen flow rate from 5 to 15 L/min changed FiO_2 only 5% to 7%. However, at these tidal volumes ($V_t \leq$ 100 mL), an increase in the supplemental oxygen flow resulted in a 100% to 200% increase in the tidal volume measured in the model. Because of these unpredicted increases in the actual tidal volumes delivered, it would be important for rescuers to continuously monitor chest excursion when supplemental oxygen is administered to determine the effects of each delivered breath.

The results of this study also indicate that when supplemental oxygen is delivered at a flow rate of 15 L/min, an $FiO_2 \leq .60$ results. Although a greater FiO_2 can be achieved with ventilation rates of 12 breaths/min, current guidelines established by the American Heart Association recommend a respiratory rate of approximately 16 to 20 breaths/min (5). Because of the potential risk of gastric dilatation, gastric perforation, or pneumothorax caused by the addition of supplemental oxygen we suggest that for infants, supplemental oxygen flow rates be limited to 5 L/min when using this device, since little increase in FiO_2 is achieved beyond this flow rate. Finally, we recommend that additional studies of similar devices be performed to: 1) examine the potential for adverse consequences resulting from product design or in-house modifications prior to pediatric use, and 2) determine the actual FiO_2 that can be delivered with varying oxygen flows.

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