

Effectiveness of Breathing through Nasal and Oral Routes in Unconscious Apneic Adult Human Subjects

A Prospective Randomized Crossover Trial

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ABSTRACT

Background: The authors hypothesized that mouth ventilation by a resuscitator *via* the nasal route ensures a more patent airway and more effective ventilation than does ventilation *via* the oral route and therefore would be the optimal manner to ventilate adult patients in emergencies, such as during cardiopulmonary resuscitation. They tested the hypothesis by comparing the effectiveness of mouth-to-nose breathing (MNB) and mouth-to-mouth breathing (MMB) in anesthetized, apneic, adult subjects without muscle paralysis.

Methods: Twenty subjects under general anesthesia randomly received MMB and MNB with their heads placed first in a neutral position and then an extended position. A single operator performed MNB and MMB at the target breathing rate of 10 breaths/min, inspiratory:expiratory ratio 1:2 and

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What We Already Know about This Topic

- Mouth-to-mouth breathing has been a standard ventilation technique during cardiopulmonary resuscitation, but its contribution to patient outcomes recently has been questioned

What This Article Tells Us That Is New

- Mouth-to-nose breathing produced more effective ventilation than did mouth-to-mouth breathing during general anesthesia in subjects without paralysis
- This result suggests the possibility of better patient outcomes with mouth-to-nose breathing during cardiopulmonary resuscitation

peak inspiratory airway pressure 24 cm H₂O. A plethysmograph was used to measure the amplitude change during MMB and MNB. The inspiratory and expiratory tidal volumes during MMB and MNB were calculated retrospectively using the calibration curve.

Results: All data are presented as medians (interquartile ranges). The rates of effective ventilation (expired volume > estimated anatomic dead space) during MNB and MMB were 91.1% (42.4–100%) and 43.1% (42.5–100%) ($P < 0.001$), and expired tidal volume with MMB 130.5 ml (44.0–372.8 ml) was significantly lower than with MNB 324.5 ml (140.8–509.0 ml), regardless of the head position ($P < 0.001$).

Conclusions: Direct mouth ventilation delivered exclusively *via* the nose is significantly more effective than that delivered *via* the mouth in anesthetized, apneic adult subjects without muscle paralysis. Additional studies are needed to establish whether using this breathing technique during emergency situations will improve patient outcomes.

CONVENTIONAL cardiopulmonary resuscitation (CPR), mouth-to-mouth breathing (MMB) and chest compression, have been practiced for more than 50 yr. It has been believed that many lives were saved using this technique. However, outcome studies after CPR were not conducted until the 1990s. Recently, several groups reported that conventional CPR of adults with MMB performed by lay rescuers did not produce greater outcome benefits than did chest compression alone (CCA).^{1–7} These studies have

led to the belief that during resuscitation of an adult victim, ventilation is unnecessary, at least during the early phase of CPR. Therefore, in 2008, the American Heart Association recommended CCA for CPR.⁸ However, the new guidelines state the outcome of CCA CPR appears to be equivalent to that of conventional CPR.⁹ The rationale is that CCA may generate sufficient ventilation to match the reduced cardiac output produced by chest compression, and MMB diverts efforts and time away from chest compression, leading to a reduction of cardiac output and perfusion pressure.^{10,11} This notion appears logical. However, the effectiveness of ventilation produced by MMB and/or by CCA during CPR has never been determined. Perhaps CCA can generate as much ventilation as MMB, or perhaps MMB produces as little ventilation as chest compression. Nevertheless, the survival rates measured after using these two differing approaches are similar and low.¹⁻⁷ An important question that remains regarding lay-rescuer-performed CPR is whether MMB can provide adequate ventilation but does not improve outcome. Because victims of noncardiac origin should, but do not, gain any benefit from MMB,^{6,7} it seems unlikely effective ventilation is ever achieved with MMB.

One animal study demonstrated that CCA resulted in a much lower rate of return to spontaneous circulation than did chest compression plus ventilation.¹² Another laboratory study in large animals showed no difference in the survival rates between animals receiving ventilation and those receiving no ventilation, but the CCA group developed more severe hypoxia than did those receiving ventilation.¹³ This implies that the pulmonary reserve of oxygen is insufficient when ventilation is not provided during CPR. A recent study of intubated humans reported the tidal volume generated by CCA is approximately 41.5 ml, far less than the anatomic dead space.¹⁴ Clearly, CCA does not produce much alveolar ventilation, even if airway patency is ensured. In reality, the upper airway is most likely obstructed when MMB is performed because upper airway obstruction frequently occurs in the supine position in unconscious individuals¹⁵ and during sleep in patients with obstructive sleep apnea.¹⁶ In addition, the generation of adequate ventilation in the absence of a nasal or oral airway is challenging, even for well-trained anesthesia care providers.¹⁷ Therefore, MMB during a lay-rescuer-performed CPR in an adult victim is unlikely to generate sufficient ventilation. The outcome of conventional CPR for pediatric patients is significantly better than that with CCA.¹⁸ If sufficient ventilation is not achieved, the elimination of rescuer ventilatory efforts would have no impact on the outcome of CPR. If ensured sufficient ventilation does translate into a better outcome of conventional CPR, then optimization, not abandonment, of ventilation should produce greater outcome benefit.

It is well known that ventilation *via* the nose leads to improved pulmonary ventilation in three different situations: during anesthesia in adults¹⁹ and infants,²⁰ when obstructive apnea occurs during sleep,^{21,22} and during pediatric

CPR.²³ In each of these settings, ventilation *via* the nose has been shown to be superior to ventilation *via* the mouth in unconscious, supine humans. Therefore, we hypothesize that ventilation *via* the nasal route (mouth-to-nose breathing [MNB]) would maintain a more patent airway and produce more effective pulmonary ventilation than would ventilation *via* the oral route (MMB) during adult emergency ventilation. The goal of our current study was to determine whether nasal route ventilation is more effective and consistent than the oral route in anesthetized, apneic, adult volunteers with a normal circulation.

Materials and Methods

This study was approved by the Massachusetts General Hospital Human Research Committee (Boston, Massachusetts), and written informed consent was obtained from all study subjects.

A total of 24 subjects, 18–60 yr old, were enrolled in this study after giving their consent. All subjects required general anesthesia, had a preoperative physical status of I or II as defined by the American Society of Anesthesiology, were able to breathe through both their nose and mouth, and had no known contraindications to mask ventilation.

After the subjects received preoperative medications, the following were placed: an electrocardiogram, noninvasive blood pressure, transcutaneous oxyhemoglobin saturation (SpO₂) monitors, and a two-belt rib-cage–abdomen inductance plethysmograph (Respirace Calibrator; Ambulatory Monitoring, Inc., Ardsley, NY). Two patients had partial dentures, and no patients were edentulous. Adequate ventilation with a facemask was ensured in all subjects before the start of the study. A CPR face shield (CPR Life Mask Face Shield; CFT, Inc., Phoenix, AZ) covered the mouth or nose of the subject (fig. 1A). Anesthesia was induced with an intravenous bolus of propofol (1–2 mg/kg) and fentanyl (50–150 μg) and maintained with additional boluses of propofol. Upon cessation of spontaneous breathing, subjects were ventilated *via* MMB or MNB delivered by an operator (investigator). The intraoral pressure of the operator (investigator) was measured *via* a flexible tube in the operator's mouth that connected to carbon dioxide/pressure/gas flow sensors (NICO Cardiopulmonary Management System, Model 7300; Respironics Corp., Murrysville, PA). The profiles of the inspiratory airway pressure during MMB and MNB were recorded. The pressure trace was also displayed and visible to the operator, who adjusted efforts to achieve a target peak airway pressure (PIP) of 24 cm H₂O. The operator inhaled 100% oxygen *via* a partial rebreathing mask before delivering each breath. If the patient's SpO₂ decreased to less than 95%, full facemask ventilation by an independent anesthetist was provided to increase the SpO₂ to greater than 95%.

Step One. The study began with the subject's head in a neutral position. Breaths were delivered at a rate of approximately 10 breaths/min with an inspiratory time of approximately 2 s during MNB and MMB. Two interventions were

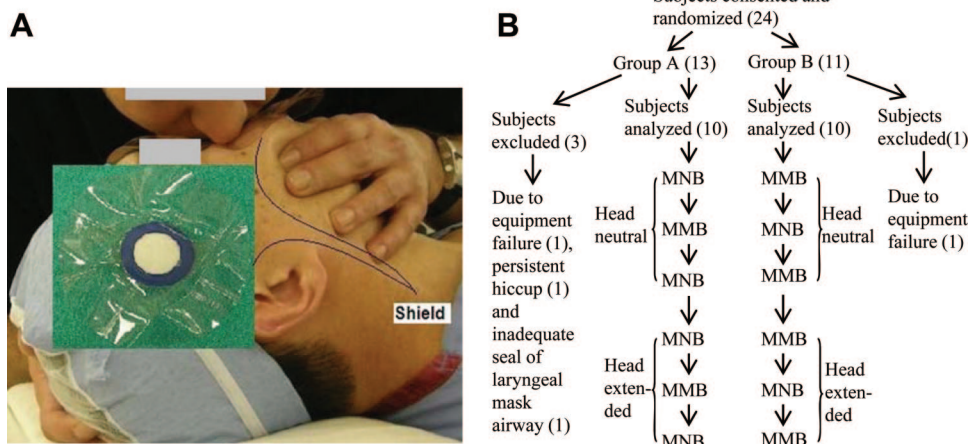


Fig. 1. Algorithm of the study and demonstration of mouth-to-nose breathing. (A) Demonstration of mouth-to-nose breathing and the location of the shield (*inset*). (B) The algorithm of the study, mouth-to-mouth *versus* mouth-to-nose breathing, in head neutral and extended position. MMB = mouth-to-mouth breathing; MNB = mouth-to-nose breathing.

used wherein the operator (investigator) delivered MNB or MMB (fig. 1B). The sequence of ventilatory maneuvers was randomized into two groups: in group A, subjects received MMB that lasted for 1 min followed by MNB (1 min) and MMB again (1 min); in group B, subjects received MNB that lasted for 1 min followed by MMB (1 min) and MNB again (1 min). During MMB, one of the operator's hands pinched the patient's nose closed, and the other stabilized the lower jaw, maintaining the head in a neutral position. During MNB, one of the operator's hands closed the jaw, and the other maintained the patient's head in a neutral position.

Step Two. The protocol for Step Two was identical to that of Step One except that the patient's head was maintained in an extended position.

Step Three. After Step Two was completed, the subject was intubated with an endotracheal tube or laryngeal mask airway. The calibration curve for the plethysmograph was generated as described previously.²⁴ Specifically, the calibration curve was created using the delivered tidal volume, the measured expired tidal volume, and the amplitude changes of the plethysmograph readings during mechanical inspiration and expiration provided by the anesthesia ventilator. Then the inspiratory and expiratory tidal volumes during MMB and MNB were calculated retrospectively using the calibration curve from each subject. The rate of effective ventilation was calculated by the number of the breaths with expired tidal volume > the estimated anatomic dead space (2.2 ml/kg ideal body weight) divided by the total number of the breaths in each breathing pattern for any individual subject.

Statistical Analysis

Based on the data obtained from our pilot study ($n = 28$) using nasal mask *versus* oral mask ventilation (data not shown), the volume of carbon dioxide removed per breath divided by the PIP (carbon dioxide/PIP) was used to calculate the sample size of this study. A sample size of 20 allowed us to detect a difference of 0.7 times SD or larger between the

two ventilatory methods with 80% power. For example, this translates into a more than 0.28 ml/cm H₂O mean difference in carbon dioxide/PIP, assuming SD of 0.4 (ml/cm H₂O). We planned to enroll 25 subjects, assuming a failure rate of 20%.

Statistical analysis was performed with a commercially available statistical package (SPSS, Version 12.0; IBM Corporation, Armonk, NY). The null hypothesis is that there is no difference in tidal volume and effective rate of ventilation achieved with MMB and MNB; analysis was performed with a two-sided test. Data are presented as mean \pm SD for demographic data or as median values with interquartile ranges for respiratory parameters. Differences between nasal and oral route ventilation were analyzed by the Wilcoxon signed rank paired test for continuous variables. A P value <0.05 was considered significant.

Results

Twenty-four subjects were randomized (fig. 1B). One subject in group A was excluded because of persistent hiccups during the study. Two subjects in group A and one in group B were excluded because of monitoring equipment failure. Demographic data are listed in table 1. There were no differences in the demographic data between groups A and B.

The respiratory parameters measured during MNB and MMB are listed in table 2. There were no differences in the PIP during MNB and MMB in head neutral or head extended position (fig. 2A). When the data at head neutral and head extended position were pooled, the PIP during MMB was 7% higher than that during MNB (table 2). There was no significant difference in pressure curve profiles measured in the operator's mouth (fig. 2B) during MNB and MMB with the subject's head in the neutral or extended positions. The rates of effective ventilation (fig. 2C) and the expired tidal volume (fig. 2D) during MNB were significantly greater than those achieved during MMB when the head was

Table 1. Demographic Data of Subjects

	Group A (n = 10)	Group B (n = 10)	P Value
Age (y)	51.2 ± 12.4	40.5 ± 7.9	0.024
Ratio of male-to-female	5:5	4:6	1.000
Height (cm)	168.9 ± 8.1	167.4 ± 10.0	0.711
Weight (kg)	83.0 ± 11.3	87.7 ± 13.9	0.420
Body mass index (kg/m ²)	29.2 ± 4.3	31.5 ± 5.5	0.301
Neck circumference (cm)	42.6 ± 3.6	43.7 ± 5.1	0.564

Values are mean ± SD. Intervention sequences are MNB → MMB → MNB (group A) and MMB → MNB → MMB (group B). The study was conducted in both the head neutral and head extended positions.

MMB = mouth-to-mouth breathing; MNB = mouth-to-nose breathing.

in a neutral position ($P < 0.001$). No significant differences (two-sided Wilcoxon rank sum test) were observed in the rates of effective ventilation or tidal volumes when the sequence of ventilation was varied ($P < 0.05$). The inhaled tidal volume (398.5 [168.3–583.8] ml) was significantly larger (15%) than the corresponding expired volume (341.0 [157.8–571.8] ml) during MNB with the head in an extended position ($P = 0.009$).

Discussion

The most important findings of this study are (a) MNB is more effective than MMB when the head is in a neutral position, and (b) the expired tidal volume is smaller than the corresponding inspired tidal volume during MNB in the head extended position. These results suggest that direct ventilation *via* the subject's nose may result in more effective ventilation than that *via* the mouth during emergency situations, such as CPR.

Lay-rescuer-initiated emergency ventilation is almost exclusively performed using MMB. The historical choice of MMB appears to be based on Safar's studies, which showed that MMB generated adequate ventilation and was able to maintain arterial oxygen saturation above 90%,^{15,25,26} whereas MNB produced expiratory airway obstruction in a

Table 2. Comparison of Ventilatory Parameters Obtained with Mouth-to-mouth and Mouth-to-nose Breathing Regardless of Head Position

	MMB	MNB	P Value
Rate of effective ventilation (%)	43.1 (1.3–95)	91.1 (42.5–100)	<0.001
Inhaled V_T (ml)	136 (43.5–355.5)	320 (141–533.5)	0.001
Expired V_T (ml)	130.5 (44.0–372.8)	324.5 (140.8–509)	0.001
PIP (cm H ₂ O)	25.9 (23.2–30.2)	28.0 (24.1–32.5)	0.024

Data were pooled from the head neutral and head extended positions (n = 20) and presented as the median (interquartile range). The rate of effective ventilation was calculated by the number of breaths with expired tidal volume > the estimated anatomic dead space (2.2 ml/kg of ideal body weight) divided by the total number of the breaths in each breathing pattern for any individual subject.

MMB = mouth-to-mouth breathing; MNB = mouth-to-nose breathing; PIP = peak inspiratory airway pressure; V_T = tidal volume.

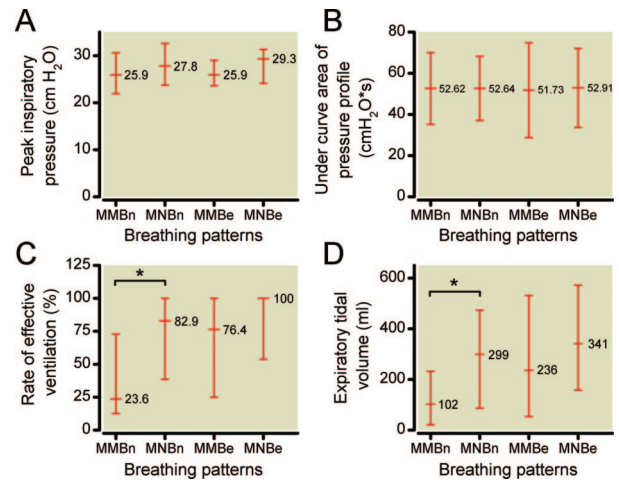


Fig. 2. Comparison of ventilatory parameters obtained with mouth-to-nose versus mouth-to-mouth breathing at head neutral versus head extended position. The PIP, airway pressure profile (area under the airway pressure curve during inspiration phase), rate of effective ventilation, and expired tidal volume are presented in A, B, C, and D, respectively. The data in A, C, and D are presented with median (interquartile range, 25–75%). The data in B are presented with mean ± SD. * $P < 0.001$. MMBe = mouth-to-mouth breathing with head extended position; MMBn = mouth-to-mouth breathing with head neutral position; MNBe = mouth-to-nose breathing with head extended position; MNBn = mouth-to-nose breathing with head neutral position; PIP = peak inspiratory airway pressure.

study of two subjects.²⁷ However, a comparison of the breathing effectiveness *via* MMB versus MNB was never conducted in more than two subjects. No additional study was performed either in a controlled situation, such as during anesthesia, or during lay-rescuer-performed CPR.

The scenarios used in the current study closely approximate the conditions of emergency ventilation during CPR. We evaluated the effect of head position on ventilation, with a neutral head position causing greater difficulty obtaining optimal ventilation and a head extended position allowing more optimal ventilation. We demonstrated a markedly higher rate of effective ventilation during MNB than during MMB in adults with a neutral head position (fig. 2C).

We are aware that MMB has been well studied.^{15,24,26,27,28} However, these studies were not intended to

compare the effectiveness of the ventilation *via* the nasal route with that *via* the oral route. We also realize that before the systematic studies of MMB, MNB had been extensively and effectively used to ventilate patients with polio by Elam.²⁵ However, to our knowledge, this study is the first to compare systemically the effectiveness of MMB and MNB in the same unconscious adult subjects. We have demonstrated that MNB is superior to MMB and can truly provide ventilation in differing head positions, even with the head in the neutral position, where the upper airway is more likely obstructed during lay rescuer CPR.

We noted, as reported previously,²⁹ mild expiratory airway obstruction during MNB when the head was extended, as evidenced by the expired tidal volume becoming smaller (15%) than the corresponding inhaled tidal volume. This is unlikely to be caused by gastric insufflations because the peak inspiratory airway pressure was less than 25 cm H₂O. We did not notice any clinical signs indicating gastric insufflations. It is also unlikely that the discrepancy was caused by undetected leakage because our tidal volume was calculated by the RespiTrace. However, it is important to note that during CPR, mild expiratory airway obstruction can be overcome by the positive intrathoracic pressure generated by chest compression. We speculate that expiratory airway obstruction is likely to be clinically irrelevant, but this requires additional study.

The most likely cause of the less effective oral route ventilation, MMB, in our study is upper airway obstruction. We observed a gross outward movement of the cheeks during inspiration during MMB; this was rarely seen during MNB. Oral insufflations *via* the mouth may have generated additional dead space ventilation because the gas contained in the distended oral cavity does not participate in gas exchange. This also indicates that nasal route ventilation might maintain a more patent airway, probably by displacing the soft palate and tongue forward. Therefore, we speculate that switching to nasal route ventilation from full facemask ventilation or MMB will improve ventilation of patients receiving CPR. However, this hypothesis requires additional study. Nevertheless, the current study provides evidence that nasal route ventilation can generate more effective ventilation in anesthetized patients whose airway physiology mimics that of the adult victim requiring CPR. If adequate ventilation using MNB does not translate into an improved outcome, then ventilation as administered by lay rescuers would not be beneficial and CCA should be performed. A recent study during pediatric CPR demonstrated that MMB improves the outcome of CPR.¹⁸ However, many factors can contribute to the difference in outcome between the adult and pediatric populations. One possibility is that pediatric victims receive more effective ventilation because of their high respiratory compliance, and the adult victim may be underventilated because of, for example, a lower compliance.³⁰ Another possibility is the difference of the pharyngeal collapsibility between adults and children. Pharyngeal clos-

ing pressures of children without obstructive sleep apnea are higher than those of adults without obstructive sleep apnea. Of course other factors may also contribute to more effective ventilation with MMB in the pediatric population than in adults.

Because lay rescuers often encounter airway obstruction when performing MMB,³¹ we believe the inability to demonstrate any additional benefit of MMB during lay-rescuer-performed CPR may result from (a) MMB, together with head tilt and jaw thrust, being difficult to learn and perform correctly, and (b) the oral route appearing not to be the optimal route for ventilation. Although the current study was not intended to test the rescuer's performance of MMB, the rescuer constantly encountered difficulty performing the "chin up" maneuver while attempting to obtain a good seal and provide positive pressure ventilation during MMB. In contrast, it is easier to do this with MNB because the rescuer's mouth pushes against a more rigid surface.

There are a number of limitations to our study. First, the study was not performed during actual CPR; it was performed in apneic subjects with normal hemodynamics. However, we believe the mechanism of airway obstruction during general anesthesia without muscle paralysis is similar to that occurring during CPR. Second, we conducted this study with subjects' heads in the neutral and extended positions. However, other head positions may be encountered by lay rescuers during CPR. Third, we did not perform blood gas analysis and were not able to verify more effective ventilation and lower arterial carbon dioxide partial pressure achieved with MNB than with MMB. However, we believe that the higher tidal volume with MNB should have resulted in a lower arterial carbon dioxide partial pressure than with MMB. Fourth, we did not determine intraoperator variability because we had a single operator (investigator) perform both MNB and MMB because our primary goal was to compare the effectiveness of ventilation *via* the two routes. Additional study is needed to address the concern of operator variability. Fifth, it was impossible to perform this study in a blinded manner. This could have biased the investigator's breathing efforts during MMB and MNB, although the PIPs and airway pressure curve profile in both approaches were measured and not significantly different. We did not conduct an intent-to-treat analysis because we could not collect respiratory data if we could not achieve an adequate mask seal or when monitoring equipment failed. Superiority of ventilation *via* the nose achieved during anesthesia may not be reproduced in field CPR. However, as mentioned, the mechanisms of upper airway obstruction during these two scenarios are similar.³² Finally, it remains to be determined if the nose is a better orifice for ventilation than the mouth and, most importantly, if MNB produces better outcomes than conventional CPR or CPR with CCA. Because a certain percent of the general population are mouth breathers,³³ MMB should be an alternative if MNB is unsuccessful.

Mouth-to-nose breathing is more effective than MMB in anesthetized, apneic adult subjects without chemical paralysis. Field studies evaluating the ease and effectiveness of MNB are required to determine whether this mode of ventilation can produce better patient outcomes after CPR.

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ANESTHESIOLOGY REFLECTIONS

Belskie's 1971 Medallion of John Snow



The chloroformist to Queen Victoria for the 1853 and 1857 childbirths of, respectively, Prince Leopold and Princess Beatrice, Dr. John Snow (1813–1858) is widely celebrated as the “Father of Epidemiology.” Snow’s research helped London combat the waves of cholera which swept the city (*right*). Sadly, a brain hemorrhage felled John Snow at 45 years of age. Had Snow lived to face Abram Belskie (1907–1988), the sculptor who would capture the physician’s likeness for the Presidential Art Medal “Great Men of Medicine Series” (*left*), Snow would have met a forensic pioneer in the art of reconstructing facial features from skeletal remains. (Copyright © the American Society of Anesthesiologists, Inc. This image also appears in the *Anesthesiology Reflections* online collection available at www.anesthesiology.org.)

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