A Unidirectional Breathing Pattern Improves Breathing Efficiency in Subjects With Severe COPD

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BACKGROUND: Unidirectional breathing (UB), nose-in mouth-out (NMB) or vice versa, is thought to create PEEP, stabilize small airways, and increase expiratory flow and exhaled tidal volume (V_T) in patients with expiratory obstructive disorders. However, the exact mechanism providing the benefits of UB remains unknown. Our hypothesis was that the benefits of UB are achieved mainly through reduction of upper airway dead space. METHODS: Sixteen stable COPD patients requiring oxygen use at home were enrolled in this prospective study at a tertiary health care center. A nasal mask and a mouthpiece were used, each having a removable one-way valve to direct the breathing pattern. Four experimentally defined patterns of spontaneous breathing, NMB, mouth-in nose-out (MNB), nose-in nose-out (NNB), and mouth-in mouth-out (MMB), were compared. Each breathing pattern lasted 5 min followed by a 5-min rest period. A NICO device continuously monitored respiratory parameters. The functional anatomical dead space volume (V_D) and expired V_T values were determined. Breathing efficiency (BE) was calculated as alveolar V_T divided by expired volume. RESULTS: Functional anatomical V_D was higher in bidirectional breathing (BB) (overall: 207.4 ± 7.9 mL; MMB: 232.5 ± 72.7 mL; NNB: 182.2 ± 75 mL) compared to UB (overall: 178.1 ± 87.2 mL; NMB: 176.9 ± 91.3 mL; MNB: 179.3 ± 83.2 mL) ($P < .001$). BE achieved with UB (overall: 76.2 ± 6.5%; NMB: 76.8 ± 6.8%; MNB: 75.6 ± 6.3%) was higher than that with BB (overall: 66.2 ± 0.09%; MMB: 64.3 ± 0.10%; NNB: 68.1 ± 0.08%) ($P < .001$). The difference in BE between UB and BB was more pronounced with small V_T values (UB: 73.8 ± 0.08; BB: 49.4 ± 0.09) than with large V_T values (UB: 77.3 ± 0.06; BB: 63.0 ± 0.07) ($P < .001$). CONCLUSIONS: Our data suggest that a reduction in functional anatomic V_D may be the underlying mechanism for the benefits associated with UB in COPD patients. (ClinicalTrials.gov registration NCT00784004.) *Key words: pursed lip breathing; unidirectional breathing; COPD; dead space; breathing efficiency.* [Respir Care 2014;59(10):1487–1493. © 2014 Daedalus Enterprises]

Introduction

Unidirectional breathing (UB) is frequently used by patients with COPD in pulmonary rehabilitation programs in the form of pursed-lip breathing to better manage dyspnea during activities of daily life. Faling[1] described UB as "usually the easiest breathing technique to learn and it is often (but not uniformly) employed instinctively by those who benefit from its use, patients inhale through the nose over several seconds with the mouth closed and then exhale slowly through the mouth." Although several hypotheses[2-6] have been proposed to explain this phenomenon,

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Drs Jiang and Kacmarek have patented a device that assists in assuring unidirectional breathing. However, this device has not been developed for manufacture or licensed to any company. Dr Kacmarek has received research grants from Covidien and Hollister and an honorarium for lecturing from Maquet and is a consultant for Covidien.

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the exact mechanism associated with the benefits of UB is still not well understood. Many believe that UB creates a PEEP, stabilizing small airways and increasing expiratory flow and tidal volume (V_T) in patients with expiratory obstructive disorders.[2,3]

It has been observed that the anatomical dead space volume (V_D) is ~150 mL for an adult (1 mL/pound of ideal body weight).[7] In normal subjects breathing quietly, anatomical V_D occupies about one third of the total V_T. However, in patients with respiratory failure, breathing shallowly and rapidly, anatomical V_D composes a large portion of the V_T.

In a previous study,[8] we demonstrated in 10 healthy volunteers that UB resulted in a significant reduction of functional anatomical V_D and improvement in breathing efficiency (BE) both with normal and variable V_T values. In the present study, we hypothesized that (1) the benefits observed from UB, breathing in through nose and out through mouth, in stable COPD patients are achieved by a reduction of dead space; and (2) that a combination of two simple mask pieces designed to force patients to breathe in through their nose and out through their mouth would reduce dead space ventilation and improve gas exchange in patients with chronic ventilation failure.

QUICK LOOK

Current knowledge

Unidirectional breathing (UB), in through the nose and out through the mouth, is thought to increase end-expiratory pressure, stabilize small airways, and facilitate expiratory flow and exhaled tidal volume (V_T) in obstructive lung disease.

What this paper contributes to our knowledge

UB results in a reduction in functional anatomical dead space volume and improved ventilation efficiency in patients with obstructive lung disease. The impact on efficiency is greater at smaller V_T values.

Methods

After obtaining Massachusetts General Hospital Institutional Review Board approval for the study protocol, patients with COPD and requiring home oxygen therapy were recruited. Patients with facial deformities, heavy beards, or moustaches preventing a good seal between the mask and the face; those who had claustrophobia and could not wear the masks; those who were hemodynamically unstable or pregnant; or those who required continuous, noninvasive, positive-pressure ventilation were excluded. Sixteen adult out-patients with documented stable COPD on home oxygen therapy were enrolled. All provided written informed consent for the study. The study procedures were performed in the research laboratory of the Department of Respiratory Care on the Massachusetts General Hospital main campus.

All subjects' lung functions were assessed prior to breathing through the unidirectional flow masks using a portable spirometer (Spirobank II spirometer, Smiths Medical PM, Waukesha, Wisconsin). All subjects were then given at least 30 min to rest and re-establish their normal resting breathing pattern before beginning the study. Their baseline heart rate and S_{pO_2} were recorded. These parameters were continuously monitored throughout the study with the pulse oximeter on a noninvasive cardiac output device (NICO, Philips Respironics, Murrysville, Pennsylvania). Oxygen was delivered to all subjects via the study masks at a rate corresponding to their home oxygen treatment regimen and at the same time maintaining the subjects' S_{pO_2} at their baseline level but in all cases above 92%. A nasal mask (vinyl nasal disposable mask, Philips Respironics) and a mouthpiece (Oracle 452 Oral CPAP/BiPAP mask, Fisher & Paykel Healthcare, Auckland, New Zealand), each having a removable one-way valve to direct the breathing pattern, were employed for all study procedures (Fig. 1). Resistance to flow through these one-way valves was 3 cm H_2O/L/s.

Four different experimentally defined spontaneous breathing patterns were applied using these masks. (1) Breathing in through the nose only and out through the mouth only (nose-in mouth-out [NMB]). This pattern was achieved by wearing both the nasal mask and mouthpiece and placing the one-way valves in a way that air could enter only via the nasal mask and leave only via the mouthpiece. (2) Breathing in through the mouth only and out through the nose only (mouth-in nose-out [MNB]). This pattern was achieved by wearing both the nasal mask and mouthpiece and placing the one-way valves in a direction opposite of those used for the first breathing pattern (NMB). (3) Breathing in and out through the nose only (nose-in nose-out [NNB]). This pattern was achieved by wearing the nasal mask only without the one-way valve and ensuring the lips were sealed. (4) Breathing in and out through the mouth only (mouth-in mouth-out [MMB]). This pattern was achieved by wearing the mouthpiece only without the one-way valve and using a nose clip to block the nasal passage.

Air leaks were minimized by appropriate mask size. The seal on the masks was checked by asking the subject to forcefully exhale against an occluded mask generating at least 30-cm H_2O airway pressure and visually inspecting and palpating to ensure that there was no air leak discernible to the subject or investigators. Oxygen was added to maintain $S_{pO_2} > 92\%$ by O_2 flowing into a 22-mm internal diameter reservoir perpendicular to the inspiratory

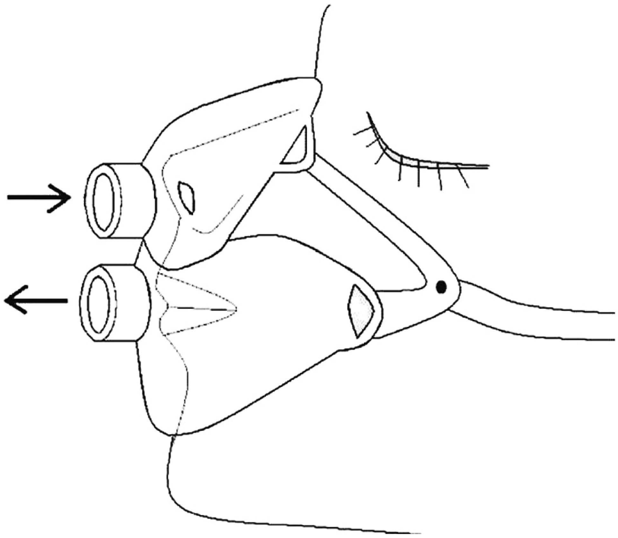

Fig. 1. Schematic illustration of the study mask. This mask contains a nasal mask and a mouthpiece. Each piece includes a one-way valve directing flow. The arrows indicate the direction of gas flow during the nose-in mouth-out breathing pattern. By changing the direction of the 2 one-way valves, mouth-in nose-out breathing was achieved. From Reference 8, with permission.

port. A NICO sensor was connected to the appropriate mask on the exhalation side during all breathing patterns. The sensor continuously recorded flow, breathing frequency, end-tidal CO_2 pressure, and calculated exhaled CO_2 volume during the study.

The order of the breathing patterns was randomly set for each subject by use of a randomization table. Each pattern lasted 5 min followed by a 5-min rest interval between each application. During the test periods, subjects were asked to relax as much as possible and breathe normally through the study mask(s). When the 4 breathing patterns were completed, the subjects were asked to rank the 4 different breathing patterns for comfort (1 being the most comfortable way of breathing and 4 being the least) and the level of difficulty in breathing (1 being the easiest way of breathing and 4 being the most difficult). Questions were read in the same way to each subject, and their answers were noted and assessed by the same investigator.

Data Analysis

Continuously recorded data were transferred from the NICO monitor to one of the research laboratory computers. Using Analysis Plus software (Philips Respironics, Murrysville, Pennsylvania), all breaths recorded for each patient during their four 5-min breathing sessions were screened. The last 10 breaths in each 5-min session were used as representative breaths for the session, as the first 4 min in each session were considered a transition and stabilization period. Expired V_T, anatomical V_D, alveolar V_T, BE, wasted ventilation, CO_2 fraction in the exhaled volume, and CO_2 clearance were calculated using the flow and CO_2 values derived from each set of 10 breaths. Anatomical V_D was calculated as $\{V_T \times [1 - (\text{mean } CO_2/\text{max } CO_2)]\}$, BE as (alveolar V_T/total V_T), wasted ventilation ratio as (V_D/total V_T), and CO_2 clearance as [(end-tidal CO_2 pressure/760) × alveolar V_T].

Table 1. Demographic Data

Subject Characteristics	Mean ± SD or *n*
Age (y)	62.4 ± 10.8
Gender (male/female)	12/4
Weight (kg)	96.8 ± 26.1
Height (cm)	172.1 ± 6.5
Body mass index (kg/m^2)	32.6 ± 9.2
Severity of COPD based on FEV_1 (%)	
≥ 80, mild obstruction	5
50–79.9, moderate obstruction	6
30–49.9, severe obstruction	3
< 30, very severe obstruction	1
Missing data	1

Statistical analysis was performed using SPSS 15.0 (SPSS, Chicago, Illinois). Data are presented as means ± SD. The 4 different patterns of breathing (NMB, MNB, MMB, NNB) were compared using repeated-measures analysis of variance to identify significant differences among the breathing patterns performed by each subject over time. Breathing patterns were further stratified into 2 categories, UB and bidirectional breathing (BB), and a paired sample *t* test was used to compare these 2 clustered groups. Post hoc analyses were performed by Bonferroni correction. A P value $< .05$ was considered significant.

Results

A total of 16 subjects were enrolled. Subject characteristics are presented in Table 1. Expired V_T values obtained with the 4 different breathing patterns were similar (NMB: 793.5 ± 411.8 mL; MNB: 774.4 ± 421.9 mL; MMB: 745.0 ± 347.6 mL; NNB: 695.5 ± 327.7 mL). When these patterns are grouped as UB (NMB and MNB) and BB (MMB and NNB) patterns, expired V_T was significantly higher in the UB group (784.0 ± 416.3 mL) than in the BB group (720.3 ± 338.2 mL) ($P = .034$). Breathing frequency was lower in the UB group (10.9 ± 4.6 breaths/min) compared to the BB group (17.4 ± 14.9 breaths/min) ($P = .023$); however, breathing frequency was similar across individual patterns (NMB: 10.6 ± 5.2 breaths/min;

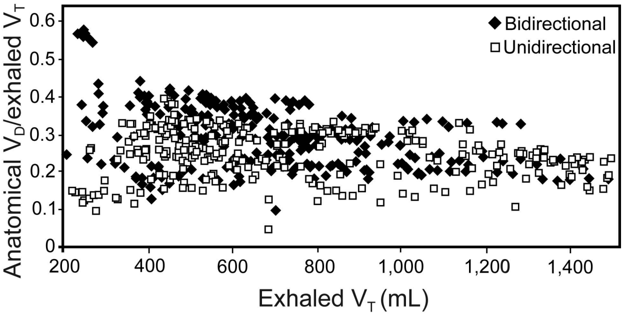

Fig. 2. Wasted ventilation ratio (anatomical dead space volume [V_D]) to expired tidal volume [V_T]) in 2 different breathing patterns.

MNB: 11.3 ± 4.1 breaths/min; MMB: 18.7 ± 17.2 breaths/min; NNB: 16.1 ± 7.4 breaths/min). Minute volume ($\dot{V}_E$) in the UB group (7.6 ± 2.8 L/min) was significantly lower than in the BB group (10.1 ± 3.6 L/min) ($P = .003$). When the 4 patterns were compared, $\dot{V}_E$ was lower in the NMB group (7.5 ± 3 L/min) than in the MMB group (10.7 ± 4.3 L/min) ($P = .048$).

Calculated anatomical V_D was lower in the UB group (178.1 ± 87.2 mL) than in the BB group (207.4 ± 77.9 mL) ($P < .001$). Anatomical V_D was significantly higher in the MMB group (232.5 ± 72.7 mL) when patterns were compared individually (NMB: 176.9 ± 91.3 mL; MNB: 179.3 ± 83.2 mL; NNB: 182.2 ± 75 mL) ($P < .001$).

Alveolar ventilation and thus BE were significantly higher in the UB group (605.9 ± 344.6 mL/breath, 76.2 ± 6.5%) than in the BB group (453.4 ± 276.3 mL/breath, 66.2 ± 0.09%) when patterns were compared in groups or individually ($P < .001$): for alveolar ventilation, NMB: 616.6 ± 341.9 mL/breath; MNB: 595.2 ± 348.0 mL/breath; MMB: 483.5 ± 285.3 mL/breath; NNB: 423.3 ± 264.5 mL/breath; and for BE, NMB: 76.8 ± 6.8%; MNB: 75.6 ± 6.3%; MMB: 64.3 ± 0.10%; NNB: 68.1 ± 0.08%.

Wasted ventilation was significantly higher in the BB group (0.30 ± 0.08) than in the UB group (0.24 ± 0.07) when patterns were compared in groups or individually (NMB: 0.23 ± 0.07; MNB: 0.24 ± 0.06; MMB: 0.34 ± 0.08; NNB: 0.27 ± 0.06) ($P < .001$) (Fig. 2).

When the expired V_T values were divided into low and high expired V_T by arbitrary selection of 500 mL as the cutoff point, the calculated anatomical V_D values were relatively higher in the small expired V_T group than in the large expired V_T group (Fig. 3). As a result, the difference in BE between UB and BB was more pronounced with small V_T values (UB: 73.8 ± 0.08; BB: 49.4 ± 0.09) than with large V_T values (UB: 77.3 ± 0.06; BB: 63.0 ± 0.07) ($P < .001$).

CO_2 clearance was significantly lower in the BB group (21.4 ± 14.7 mL/breath) compared to the UB group (29.3 ± 17.5 mL/breath) ($P < .001$). CO_2 clearance per each breathing pattern was 30.8 ± 18.7 mL/breath (NMB), 27.8 ± 16.2 mL/breath (MNB), 22.5 ± 13.6 mL/breath (MMB), and 21.6 ± 15.3 mL/breath (NNB). Results were similar in the NMB and MNB groups as they were in the MMB and NNB groups, while those in the NMB and MNB groups were higher than those in the MMB and NNB groups ($P < .001$) (Fig. 4).

NNB was the most preferred breathing pattern ($n = 8$). NMB was second ($n = 4$). Subjectively, subjects reported NMB as “easier to perform” than MNB because MNB “caused a dry mouth.” Comparing MMB with NNB, NNB was considered more natural than MMB.

Discussion

Our findings can be summarized as: compared with BB (NMB and MNB), UB (NNB and MMB) resulted in (1) a decrease in anatomical V_D; (2) an increase in BE; (3) an increase in V_T, a decrease in breathing frequency, and a decrease in $\dot{V}_E$; and (4) an increase in CO_2 removal per breath.

UB, specifically the NMB pattern as in pursed-lip breathing, is frequently used by COPD patients during times of respiratory distress either instinctively or as instructed by their health care provider.[9-12] Despite its widespread use in respiratory distress, the exact underlying mechanism of how this breathing pattern works remains unknown. It has been proposed that UB stabilizes the bronchial tree, reduces airway collapse and air trapping, and increases expiratory flow and V_T.[2,13] However, this theory does not explain why patients with neuromuscular disorders but with normal lung function also voluntarily choose such a breathing pattern.[14] When expiratory positive airway pressure is used to stabilize the airway, it does not produce the same effect as UB.[15] In our previous study with healthy volunteers,[8] we showed that UB resulted in a significant reduction in functional anatomical V_D and improvement in BE. To our knowledge, this is the first time that this hypothesis was tested in COPD patients; and our findings, similar to those in volunteers, also showed a significant reduction in functional anatomical V_D and an increase in BE during UB compared to BB. This may well explain why patients with respiratory stress, including those with neuromuscular disorders, instinctively choose UB. In other words, a reduction in anatomical V_D and an increase in BE may be the primary mechanism producing the benefits of UB in individuals with respiratory insufficiency.

Our findings also demonstrate that the fraction of anatomical V_D over expired V_T is reversely proportional to expired V_T. As expired V_T decreases, the fraction increases. This finding is important in patients with decompensated COPD since they have diminished V_T values and breathe

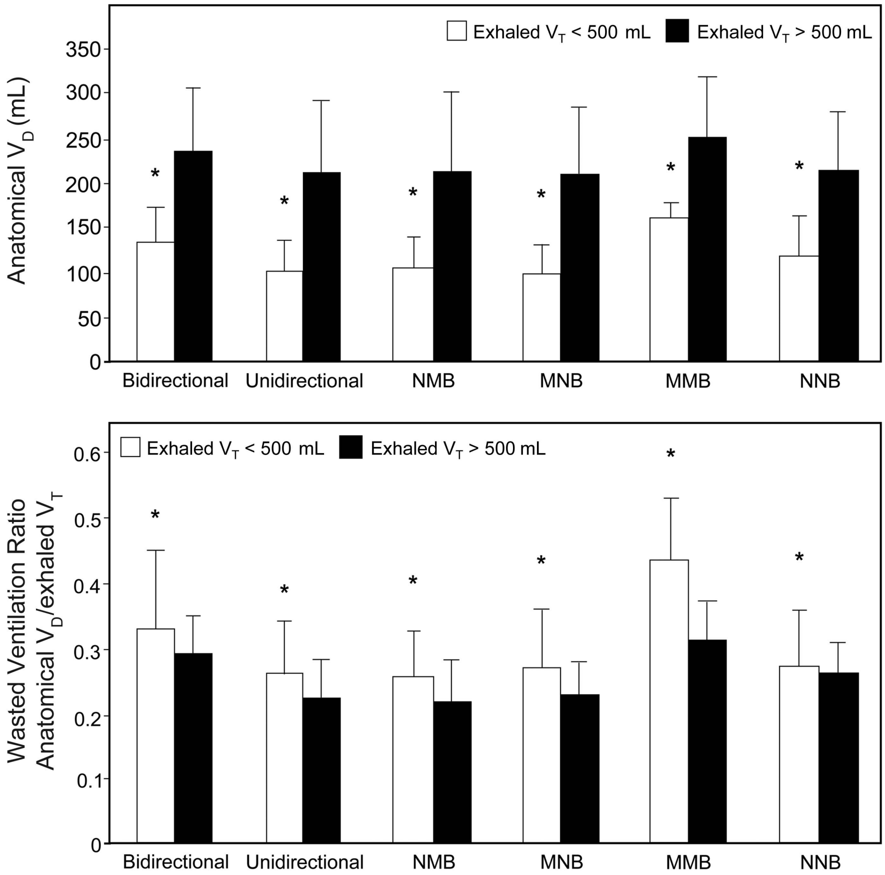

Fig. 3. Low versus high tidal volume (V_T) effect on functional anatomical dead space volume (V_D) and wasted ventilation ratio. NMB = nose-in mouth-out breathing pattern. MNB = mouth-in nose-out breathing pattern. MMB = mouth-in mouth-out breathing pattern. NNB = nose-in nose-out breathing pattern. Data are shown as mean ± SD. * $P < .001$ versus expired $V_T > 500$ mL group.

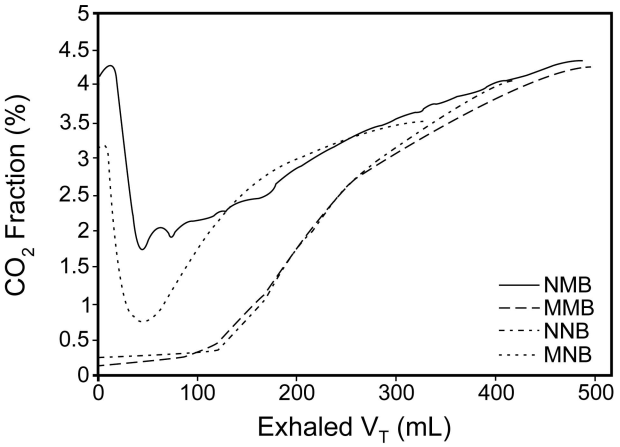

Fig. 4. CO_2 level in a representative breath for each breathing pattern from a random subject. NMB = nose-in mouth-out breathing pattern. MNB = mouth-in nose-out breathing pattern. MMB = mouth-in mouth-out breathing pattern. NNB = nose-in nose-out breathing pattern. V_T = tidal volume.

rapidly and shallowly due to respiratory muscle fatigue. Interestingly, all 16 subjects studied generated large V_T values (752 mL on average) even though all were on home oxygen therapy and well compensated. We have not tested our hypothesis on decompensated COPD patients with ventilatory muscle dysfunction and low expired V_T. However, because the increase in BE using UB is inversely related to V_T, we expect that such patients would benefit more with UB than the subjects evaluated in this study. The effect of UB on breathing frequency should also be emphasized. Study subjects had a lower breathing frequency when they were breathing unidirectionally and higher when breathing bidirectionally, which might be interpreted as a sign of increased work of breathing and decreased BE.

When standard masks are used in the ventilatory treatment of COPD patients, additional mechanical dead space is unavoidable and is another factor contributing to the decrease in BE. In UB, since air flows in one direction, any additional mechanical device on either the inspiratory or expiratory route does not create extra functional dead space. Therefore, UB, either passive or mechanically assisted, would not only reduce the dead space of the natural airway but also prevent the addition of any mechanical

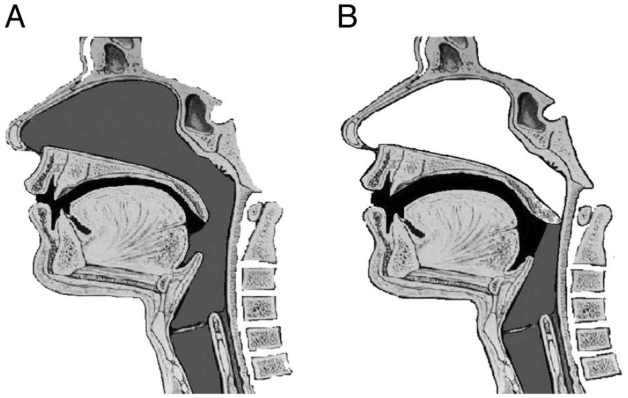

Fig. 5. Schematic illustration of upper airway anatomical dead space volume (V_D) during unidirectional breathing. A: The airway filled with CO_2-containing gas (gray) at end exhalation during nose-in nose-out breathing. This amount of CO_2-containing gas is recycled in the subsequent breath. B: The nasal and part of the pharyngeal cavity (white) filled with fresh gas at end exhalation during nose-in mouth-out breathing. The CO_2-containing gas in the oral cavity (black) is not recycled into the lung since inhalation occurs only via the nasal cavity. From Reference 8, with permission.

dead space as a result of an oxygen or noninvasive ventilation mask.

BE can also be assessed by measuring the amount of CO_2 removed per breath; the higher the CO_2 removal, the higher the BE. We found that CO_2 removal per breath was higher with UB, NMB, and MNB than with BB, MMB, and NNB. We believe that this effect was due to the extra volume of CO_2-containing gas removed during exhalation by MNB and NMB (Fig. 4); that is, with BB, the entire airway is filled with CO_2-containing gas at the end of exhalation (Fig. 5A). This CO_2-containing gas enters alveoli first before any fresh gas at a volume equivalent to the anatomical V_D. However, with UB (NMB), only a fraction of CO_2-containing gas enters alveoli during inhalation since the nasopharyngeal cavity is filled with fresh gas, not CO_2-containing gas, during the entire respiratory cycle (Fig. 5B). Therefore, UB bypasses the dead space above the larynx and functions similar to a tracheostomy.[16-18] Indeed, the reduction of dead space obtained with UB is close to that of breathing via a tracheostomy.[8]

Finally, the limitations of our study may be listed as (1) only stable and well-compensated COPD patients were enrolled. Thus, the conclusions from this study may not apply to patients in acute respiratory failure. However, it is well known that decompensated patients with respiratory failure usually breathe with small V_T values and would have at least theoretically benefited more than those in this study. (2) This was a short-term study. We did not determine if these subjects could tolerate using the masks for a long period of time. Therefore, the results from the short-term study may not be translated to long-term benefit without further studies. (3) Our study was conducted when the subjects were awake and cooperative. All subjects were able to coordinate well with each of the breathing patterns. We do not know if the subjects will be able to perform UB during sleep even with appropriate masks and unidirectional valves. (4) The use of the two masks and the resistance of the one-way valves may have affected these subjects' ventilatory patterns, altering their breathing frequency and V_T.

In conclusion, UB results in less functional anatomical V_D, less wasted ventilation, and more BE than BB. This effect was more prominent with smaller V_T values. Our findings support the suggestion that reduction in dead space may be the underlying mechanism responsible for improved BE during pursed-lip breathing.

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