

Evaluation of carbon dioxide rebreathing during exercise assisted by noninvasive ventilation with plateau exhalation valve

Yong-er Ou*
Zhi-min Lin*
Dong-ming Hua
Ying Jiang
Ya-ting Huo
Qun Luo
Rong-Chang Chen

State Key Laboratory of Respiratory Disease, National Clinical Research Center for Respiratory Disease, Guangzhou Institute of Respiratory Disease, First Affiliated Hospital of Guangzhou Medical University, Guangzhou, People's Republic of China

*These authors contributed equally to this work

Correspondence: Rong-Chang Chen
State Key Laboratory of Respiratory Disease, National Clinical Research Center for Respiratory Disease, Guangzhou Institute of Respiratory Disease, First Affiliated Hospital of Guangzhou Medical University, 151 Yanjiang Road, Guangzhou, Guangdong 510120, People's Republic of China
Tel/fax +86 20 8306 2882
Email rcchengird@163.com

Abstract: Noninvasive ventilation with a plateau exhalation valve (PEV) is often used as an adjunct to exercise to achieve a physiologic training effect in severe chronic obstructive pulmonary disease (COPD) patients. However, during exercise, with the increase of exhalation flow and respiratory rate and limited capability of PEV to exhale gases out of the circuit, it is still unknown whether CO₂ rebreathing occurs in COPD patients ventilated during exercise assisted by single-limb circuit with a PEV. A maximal symptom-limited cycle exercise test was performed while ventilated on pressure support (inspiratory:expiratory pressure 14:4 cmH₂O) in 18 male patients with stable severe COPD (mean \pm standard deviation, forced expiratory volume in 1 s: 29.5% \pm 6.9% predicted). At rest and during exercise, breathing pattern, mean expiratory flow, mean expiratory flow of PEV, and the mean inspiratory fraction of CO₂ (tidal fractional concentration of inspired CO₂ [FiCO₂]) reinsufflated from the circuit was measured for each breath. In comparison with rest, with the significant increase of mean expiratory flow (0.39 \pm 0.15 vs 0.82 \pm 0.27 L/s), fractional concentration of end-tidal CO₂ (2.6% \pm 0.7% vs 5.5% \pm 0.6%), and the significant decrease of mean expiratory flow of PEV (0.41 \pm 0.02 vs 0.39 \pm 0.03 L/s), tidal FiCO₂ significantly increased at peak exercise (0.48% \pm 0.19% vs 1.8% \pm 0.6%) in patients with stable severe COPD. The inflection point of obvious CO₂ rebreathing was 0.67 \pm 0.09 L/s (95% confidence interval 0.60–0.73 L/s). Ventilated by a single-limb tubing with PEV caused CO₂ rebreathing to COPD patients during exercise. Patients with mean expiratory flow >0.60–0.73 L/s may be predisposed to a higher risk of CO₂ rebreathing.

Keywords: carbon dioxide rebreathing, noninvasive ventilation, exercise, chronic obstructive pulmonary disease, single-limb circuit, pulmonary rehabilitation

Introduction

Exercise training is a key component of pulmonary rehabilitation. It has demonstrated significant improvements in both exercise tolerance and quality of life in patients with chronic obstructive pulmonary disease (COPD).¹ The intensity of exercise training is of great importance to yield a true physiologic effect. However, in patients with severe COPD, exertional dyspnea and leg fatigue make it impossible for the patient to maintain intensity of training for enough time to achieve a physiologic training effect.² Noninvasive ventilation (NIV) has been reported to be used as support for exercise to improve exercise tolerance and respiratory performances in patients with mild-to-severe COPD with inconsistent results.^{3–20} In these studies, one of the obvious methodological issues existed with respect to the selection of exhalation valve connected to the single-limb circuit. Evidence from Moga et al¹⁹ and Highcock et al²⁰ indicated that NIV with a single-limb circuit

with Whisper Swivel II expiratory valve (Respironics Inc., Murrysville, PA, USA) assisting exercise did not improve exercise capacity in COPD patients. Also, as previously reported by Ferguson and Gilmartin,²¹ the use of Whisper Swivel II expiratory valve during bi-level positive airway pressure (BiPAP) ventilatory assistance causes CO₂ rebreathing, which can blunt any effect of BiPAP on partial pressure of CO₂ (PaCO₂). It could not be dismissed that CO₂ rebreathing occurred with the use of the standard exhalation port thus diminishing the efficacy of NIV support. Plateau exhalation valve (PEV) or the Sanders NRV-2 plateau valve (NRV; Respironics Inc.) have been shown to be more effective in eliminating CO₂ rebreathing in patients at rest,²¹ however, the latter one prevented CO₂ rebreathing at the expense of increased expiratory resistance and work of breathing²² and sometimes it can potentially malfunction; considering these factors, the former one has been widely used.

With the use of the PEV in the circuit, the risk of CO₂ rebreathing is presumably low when the expiratory time (Te) is long enough to ensure that evacuation of the circuit is complete. However, our group have previously demonstrated that the mean leak flow of the valve at low pressure (expiratory phase) was 0.43 L/s at rest.²³ During exercise, the increase of expiratory flow due to the high levels of ventilatory requirements, and elevated breathing frequency of patients with COPD, may promote the occurrence of CO₂ rebreathing. As CO₂ rebreathing increases the drive to ventilate and the work of breathing^{22,24,25} and may have a negative impact on efficacy,^{26,27} it is important to clarify this risk.

Therefore, the aim of the present study was to evaluate whether CO₂ rebreathing occurred in COPD patients ventilated during exercise by the single-limb circuit with a PEV and to estimate a potential threshold of expiratory flow for predicting CO₂ rebreathing.

Methods

Study participants

Eighteen COPD patients were recruited from the first affiliated hospital of Guangzhou Medical University from January 2016 to March 2016. The diagnosis of COPD was confirmed by physician's diagnosis and spirometry. Patients who presented with clinical stability (no exacerbation in the previous 4 weeks and with no change in medications, in the absence of right heart decompensation signs), forced expiratory volume in 1 s (FEV₁) < 50% predicted, dyspnea as a main symptom that limited daily activities, were included in the study. Excluded criteria: individuals with obvious pulmonary bullae or facial trauma/malformation; cardiovascular disease; a history of uncontrolled

hypertension; other respiratory diseases; oxygen saturation (SpO₂) < 88% at rest; patients with musculoskeletal or neurologic disorders. Ethical approval for this study was obtained from the research ethics committee of the First Affiliated Hospital of Guangzhou Medical University, and all participants gave their written informed consent in accordance with the Helsinki Declaration.

Study design

Patients completed screening tests to determine eligibility for the study. This study comprised of two visits: 1) Visit 1 included a thorough clinical assessment, pulmonary function tests, baseline arterial blood gas sampling, getting used to the application of the ventilator, and completing a maximal symptom-limited-incremental cardiopulmonary exercise test; 2) Visit 2 included a maximal cycle exercise test with the participants assisted by BiPAP (Vision; Respironics Inc.) receiving 10 cmH₂O pressure support in addition to oxygen therapy. At rest and during the whole exercise process, breathing pattern, heart rate (HR), flow, pressure, CO₂ concentration, and SpO₂ were recorded until complete recovery. Before each visit, subjects kept on taking regular medicine and abstained from caffeine, heavy meals, alcohol, and major physical exertion entirely on visit days.

Pulmonary function tests

Pulmonary function tests were performed using a Quark PFT (pulmonary function testing) system (Cosmed, Rome, Italy). FEV₁ and forced vital capacity (FVC) were determined from the best of three maneuvers if the variance was within 150 mL or 5% of the FEV₁ or FVC, respectively.²⁸ Measurements were expressed as percentages of predicted normal values.^{29–31}

Oxygen delivery and ventilator setting

Oxygen was delivered to the face mask by a tube at a constant rate (5 L/min). Ventilatory assistance was delivered using a BiPAP Vision with a PEV in BiPAP spontaneous/time mode applied via a tightly fitting full face mask (Curative, Beijing, People's Republic of China). Inspiratory positive airway pressure (IPAP) was set at 14 cmH₂O, and the expiratory positive airway pressure (EPAP) was set at 4 cmH₂O and a backup respiratory frequency was set at 12 breaths/min.

Maximal cycle exercise test and intervention procedure

Maximal symptom-limited-incremental cycle exercise tests were conducted on an electronically braked cycle ergometer (Ergoselect 200 K; Cosmed, Rome, Italy). Symptom-limited

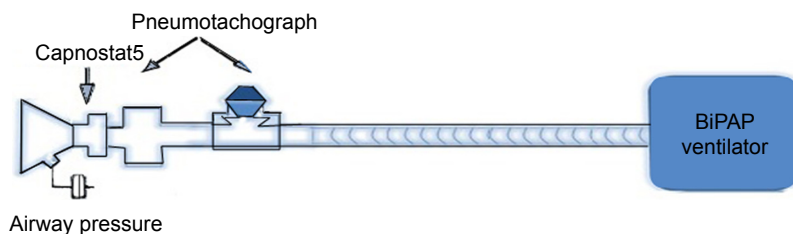


Figure 1 Experimental setup.

Notes: The facemask was attached in series with capnostat5 (mainstream CO₂ sensor), pneumotachograph, PEV (flow of the PEV was directly recorded by a pneumotachograph), ventilator tubing, and BiPAP machine. Airway pressure and flow and the volume of CO₂ delivered from the circuit at each breath were measured at the distal end of the ventilator circuit. Furthermore, to evaluate the leak flow of the PEV, another pneumotachograph was attached to the PEV.

Abbreviations: BiPAP, bi-level positive airway pressure; PEV, plateau exhalation valve.

cycle exercise test consisted of a steady-state resting period of at least 3 min followed by 1 min of unloaded pedaling at 60–65 cycles/min; the load was increased by 10 W each minute, starting at 10 W until a symptom-limited endpoint. At rest and during exercise, participants breathed through the facemask attached in series with capnostat5 (Phillips Respironics, Murrysville, PA, USA), pneumotachograph (3830A series; Hans-Rudolph Inc., Shawnee Mission, KS, USA), PEV (flow of the PEV was directly recorded by a pneumotachograph [ADInstruments Inc., Sydney, Australia]), ventilator tubing, and BiPAP ventilator (Figure 1). Mouth pressure was determined using differential pressure transducers (YH; Ying Hui Medical Devices Co. Ltd., Guangzhou, People's Republic of China) connected to pressure catheters attached to a mask side port. Capnostat5 attached to the Powerlab via NT1D Handheld CO₂/SpO₂ monitor (Newtech Inc., Shenzhen, People's Republic of China). The delay representing transit time from the sample point to the analyzer was measured beforehand. Signals of pressure, flow, and CO₂ were recorded at a frequency of 200, 200, and 100 Hz, respectively. Signals were recorded continuously using an analogic/numeric Powerlab data acquisition system (ML796; ADInstruments Inc.) running on an iMac computer (Apple Computer Inc., Cupertino, CA, USA). The flow signal was integrated to yield the volume.

Analyses were made breath by breath, after phasing CO₂ curves with flow and pressure. For each breath, inspiratory time (Ti), Te, respiratory rate (RR), inspiratory tidal volume (Vti), expiratory tidal volume (Vte), mean expiratory flow (Vte/Te), mean flow vented out from the PEV during expiration (Ex/Te), fractional concentration of inspired CO₂ (FiCO₂), and fractional concentration of end-tidal CO₂ (FetCO₂) were measured. The volume of CO₂ delivered from the circuit at each breath was calculated by integrating the CO₂ flow curve, defined as the product of inspiratory flow and CO₂ concentration curves.³² Mean inspiratory fraction of CO₂ for

each tidal volume (tidal FiCO₂), expressed as a percentage, was defined as: inspired volume of CO₂/Vti*100.

Using Origin Pro 8 software to draw a scatter plot to determine the relationship between Vte/Te (x values) and the tidal FiCO₂ (y values), apply a nonlinear curve fit to the scatter plot, if the nonlinear curve fitness was good (adjusted R²≥0.8, P<0.05), the presence of an inflection point was next determined by assuming that the Vte/Te-tidal FiCO₂ curve was made up of two straight lines and that the inflection point represented the point where these lines intersected, to find out the obvious inflection point when CO₂ rebreathing appeared. The curve was divided into two parts (A&B) at an arbitrary point, V_k, and a pair of linear regressions were performed using the data above and below this point. This yielded two regression lines, line A and line B, with correlation coefficients, rA and rB, respectively. The process was repeated many times varying the dividing point V_k so that the point where rA*rB was maximal could be determined.

Fingertip SpO₂ was measured by pulse oximetry; HR was measured by six-lead electrocardiogram; blood pressure was measured by automatic blood pressure measurement with an arm cuff during the whole process.

Statistical analysis

Data were expressed as mean ± standard deviation after testing for normal distribution (Kolmogorov–Smirnov test) unless otherwise specified. The 95% confidence interval (95% CI) was determined if appropriate. All data were analyzed using paired *t*-test. Differences were considered significant when P<0.05.

Results

In total, 18 patients with stable severe COPD completed the tests; demographic data of the 18 patients are shown in Table 1. Only one COPD patient had chronic hypercapnic respiratory failure.

Table 1 Characteristics of study subjects

Male:Female (n)	18:0
Age (years)	69.3±1.4
Height (cm)	165.6±1.2
Weight (kg)	60.2±1.9
BMI (kg/m ²)	22.0±0.6
FEV ₁ (L)	0.77±0.04
FEV ₁ (% predicted)	29.5±1.6
FEV ₁ /FVC (%)	35.0±1.5
FVC (L)	2.22±0.11
FVC (% predicted)	65.5±2.95
MVV (L/min)	33.4±1.6
MVV (% predicted)	32.8±1.8
Peak watt (W)	56.3±16.1
Peak VO ₂ /kg (mL/min/kg)	13.4±2.9
Peak VO ₂ (% predicted)	47.1±12.0
Peak VE (L/min)	28.2±6.5
Resting RR (breath/min)	18.7±3.0
Peak RR (breath/min)	29.2±5.8
Peak tidal volume (L)	0.99±0.25
Peak HR (beat/min)	115.1±11.6
PaCO ₂ (mmHg)	40.7±4.4

Note: Results are reported as mean ± standard deviation after testing for normal distribution (Kolmogorov–Smirnov test).

Abbreviations: BMI, body mass index; FEV₁, forced expiratory volume in 1 s; FVC, forced vital capacity; HR, heart rate; MVV, maximal voluntary ventilation; RR, respiratory rate; VE, minute ventilation; VO₂, oxygen uptake; PaCO₂, partial pressure of CO₂.

Table 2 Comparison of breath characteristics at rest and peak exercise in COPD patients

	COPD patients	
	At rest	Peak-exercise
IPAP (cmH ₂ O)	14.1±1.2	13.6±2.0
EPAP (cmH ₂ O)	4.1±0.2	4.5±0.4 [§]
Vte/Te (L/s)	0.39±0.15	0.82±0.27 [§]
Tidal FiCO ₂ (%)	0.48±0.19	1.8±0.6 [§]
FetCO ₂ (%)	2.6±0.7	5.5±0.6 [§]
Ex/Te (L/s)	0.41±0.02	0.39±0.03 [§]
Ti (s)	0.67±0.12	0.98±0.22 [§]
Te (s)	2.59±0.75	1.53±0.29 [§]
Vte (L)	0.92±0.27	1.21±0.31 [§]
Ex vol (L)	1.06±0.31	0.61±0.13 [§]
Ti/Ttot (%)	0.28±0.05	0.31±0.05
RR (breath/min)	17.9±4.9	27.9±4.9 [§]
SpO ₂ (%)	98.0±1.2	88.8±2.0 [§]
HR (beat/min)	88.5±10.6	119.7±8.8 [§]
Systolic blood pressure (mmHg)	120.3±11.9	174.1±8.5 [§]
Diastolic blood pressure (mmHg)	71.5±11.2	87.2±8.5 [§]

Notes: Results are reported as mean ± standard deviation after testing for normal distribution (Kolmogorov–Smirnov test). [§]P<0.01 peak-exercise vs at rest.

Abbreviations: COPD, chronic obstructive pulmonary disease; EPAP, expiratory positive airway pressure; Ex vol, the volume vented out from the exhalation valve during expiration; Ex/Te, the mean flow vented out from the plateau exhalation valve during expiration; FetCO₂, fractional concentration of end-tidal CO₂; HR, heart rate; IPAP, inspiratory positive airway pressure; RR, respiratory rate; SpO₂, oxygen saturation; Te, expiratory time; Ti, inspiratory time; Ti/Ttot, inspiratory duty cycle; Tidal FiCO₂, mean inspiratory fraction of CO₂; Vte, expiratory tidal volume; Vte/Te, mean expiratory flow.

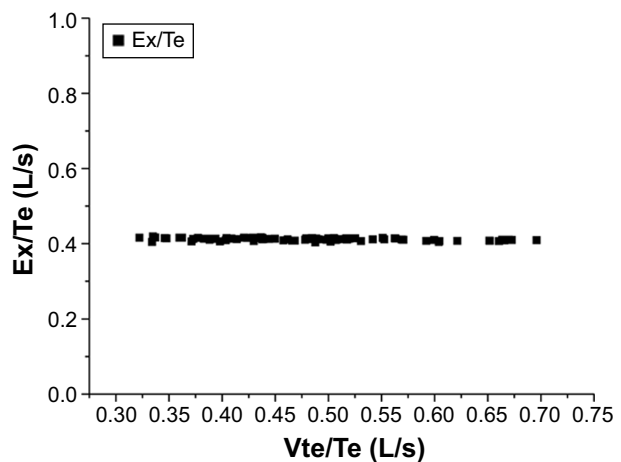


Figure 2 The changes of Ex/Te varied with Vte/Te throughout rest and exercise periods in one representative subject.

Abbreviations: Ex/Te, mean flow vented out from the plateau exhalation valve during expiration; Vte/Te, mean expiratory flow.

As can be seen from Table 2, while ventilated on pressure support (inspiratory:expiratory pressure 14:4 cmH₂O) assisted by single-limb circuit with a PEV, in comparison with rest, at peak exercise, with the increase of expiratory tidal volume, elevated breathing frequency, Vte/Te and FetCO₂, and the decrease of Ex/Te and Te, tidal FiCO₂ significantly increased (all P<0.01).

During expiration, with the increase of Vte/Te, the mean flow vented out from PEV varied from 0.41 to 0.39 L/s throughout exercise in COPD patients (Table 2; Figure 2).

Throughout rest and exercise, tidal FiCO₂ varied with Vte/Te in all subjects. In the majority of COPD patients, tidal FiCO₂ increased with increasing Vte/Te. After using Origin Pro 8 software to draw a scatter plot to determine the relationship between the Vte/Te (x values) and the tidal FiCO₂ (y values), applying a nonlinear curve fit to the scatter plot (Figure 3A), the curve fitness was good (adjusted R²>0.80, P<0.05) in 15 subjects. However, three of the COPD patients with their FEV₁ of 0.49, 0.52, and 0.61 L failed the curve fitness (adjusted R²<0.05; Figure 3B). The inflection point of obvious CO₂ rebreathing was 0.67±0.09 L/s (95% CI: 0.60–0.73 L/s; Figure 4).

Discussion

Exercise training is a key component of pulmonary rehabilitation. In patients with severe COPD, exertional dyspnea makes it impossible for the patient to maintain intensity of training for enough time to achieve a physiologic training effect.² NIV has been reported to be used as support for exercise to improve exercise tolerance and respiratory performances in patients with mild-to-severe COPD, with

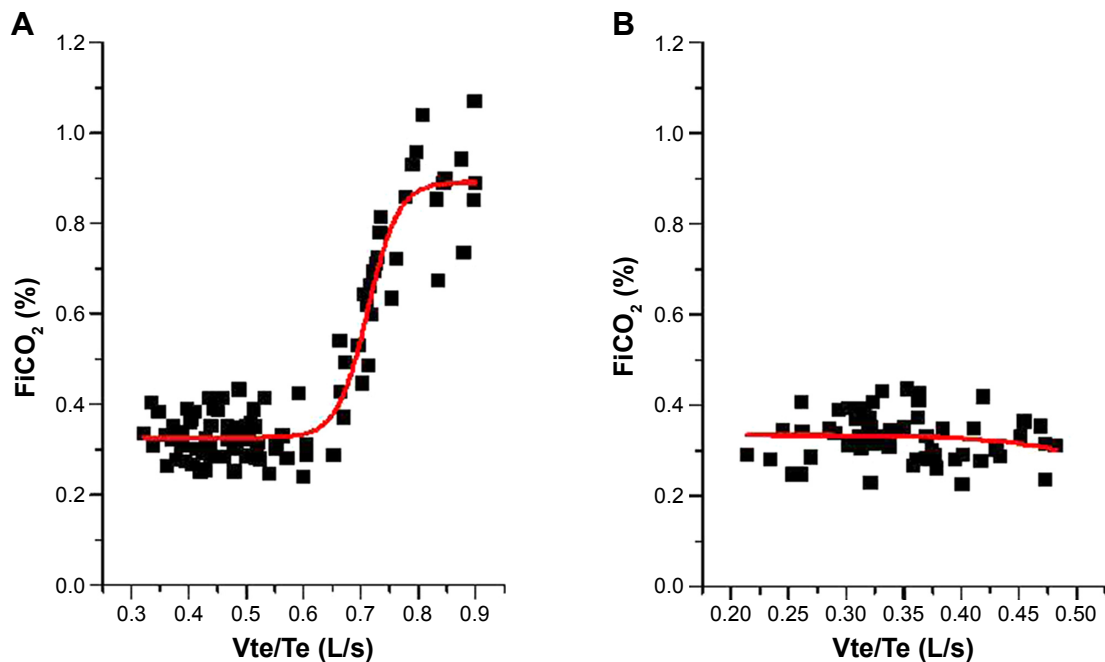


Figure 3 The changes of tidal FiCO_2 varied with Vte/Te throughout rest and exercise periods in two representative subjects (A, B).

Notes: (■) Data points are mean values of the expiratory tidal flow and fraction of inspired CO₂ of the next breath for respective subjects. (-) represents the curve that fits the scatter plot.

Abbreviations: FiCO_2 , fractional concentration of inspired CO₂; Vte/Te , mean expiratory flow.

inconsistent results.^{3–20} In these studies, one of the obvious methodological issues existed with respect to the selection of exhalation valve connected to the single-limb circuit. PEV or NRV have been shown to be more effective in eliminating CO₂ rebreathing in patients at rest,²¹ however, because NRV has the disadvantages of increased expiratory resistance and work of breathing²² and potential malfunction, PEV has been

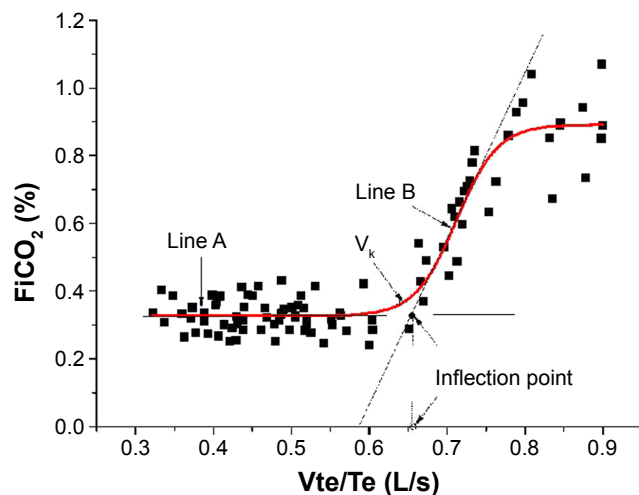


Figure 4 Typical example of analysis of nonlinear curve fitness of mean expiratory flow-tidal FiCO_2 curve.

Notes: The filled square (■) on the fitted curve (thick line) represents V_k which divides the curve to yield the best fit of two lines (A and B, thin lines). Closed circle (●) represents the calculated inflection point.

Abbreviations: FiCO_2 , fractional concentration of inspired CO₂; Vte/Te , mean expiratory flow.

widely used. In the single-limb tubing for inspiration and expiration, PEV serves to eliminate CO₂ from the breathing circuit and is an important part for decreasing dead space ventilation and improving ventilation efficiency. Former studies have found that leak flow rates of PEV remained nearly constant throughout the specified pressure range.²³ With the increasing minute ventilation during exercise, NIV with a PEV might cause CO₂ rebreathing. As far as we know through the search of Medline, there has been no report on evaluating CO₂ rebreathing in COPD patients assisted by NIV in BiPAP mode with a PEV on single-limb circuit during maximal cycle exercise test.

The main findings of this study are as follows: 1) during exercise, with the increasing total expiratory flow of the subject, the flow vented out of PEV decreased (Figure 2); 2) compared to at rest, tidal FiCO_2 increased significantly at peak exercise in COPD patients ($P < 0.01$), indicating CO₂ rebreathing occurred; 3) ventilated by a single-limb tubing with PEV during exercise, patients with $\text{Vte/Te} > 0.67 \pm 0.09$ L/s (95% CI: 0.60–0.73 L/s) may be predisposed to a higher risk of CO₂ rebreathing.

With regard to patients with severe COPD ventilated by a single-limb tubing during exercise, obvious methodological issues existed and they resulted in inconsistent outcomes for relieving dyspnea or improving exercise tolerance. Different exhalation valves and different levels of pressure support have

been reported. In previous studies, investigating the effects of a single-limb circuit with a Silenflow Exhalation valve (Weinmann, Hamburg, Germany) to deliver ventilatory assistance (IPAP: 29.5 ± 4.1 cmH₂O, EPAP: 4.38 ± 0.82 cmH₂O) during exercise in COPD with hypercapnia,^{16,17} there were controversial outcomes on the alleviation of dyspnea. Moreover, in studies by Moga et al¹⁹ and Highcock et al,²⁰ they found that BiPAP with Whisper Swivel II did not improve exercise capacity. These findings, in combination with the result found by Ferguson and Gilmartin²¹ that significant CO₂ rebreathing could occur at low expiratory pressure levels (≤ 4 cmH₂O) on single-limb circuit with Whisper Swivel Valve or other fixed-resistance exhalation devices, suggested that CO₂ may not be adequately cleared with the fixed-resistance exhalation valve both at rest and during exercise and that this blunted the efficacy of NIV. Former study has implied that such CO₂ rebreathing and dead space ventilation could be effectively eliminated by the use of NRV or the PEV.²¹ However, NRV eliminated CO₂ at the expense of increasing expiratory resistance and work of breathing,²² and sometimes it can potentially malfunction; considering these factors, PEV has been the most widely used. NIV with single-limb circuit in BiPAP mode is often used,^{11–17} pressure support (PS) setting of 10 cmH₂O has been proven to be effective to reduce dyspnea in COPD patients,^{4,5,18} and based on the mechanism of action of PEV, leak flow rates were greater at around 4–5 cmH₂O, therefore, single-limb tubing with PEV in BiPAP mode with PS setting of 10 cmH₂O (IPAP:EPAP 14:4 cmH₂O) was used in this study.

As to the measurement of CO₂ rebreathing, some research indicated a preference for measurement of CO₂ partial pressure in an arterial blood gas sample (PaCO₂),^{21,22} whereas others argued that the value of CO₂ inhaled (FiCO₂)^{33–35} offered more accurate and beneficial information. In fact, these values could be regarded as interdependent values. According to our point of view, FiCO₂ is the most representative value in rebreathing as it shows the CO₂ amount in the patient's mask at the proto-inspiratory phase. It was shown that during exercise, with the increase of expiratory tidal volume, elevated breathing frequency, and Vte/Te, and the decrease of Ex/Te, tidal FiCO₂ significantly increased (Table 2), indicating that CO₂ rebreathing occurred during exercise in this setting, which needs to be paid attention to.

Understanding the mechanisms related to the occurrence of CO₂ rebreathing is important. CO₂ rebreathing consists of rebreathing previously expired gas by the patient if such gas is not appropriately eliminated from the circuit during the ventilatory cycle, as a result of an accumulation of this

gas in the circuit. CO₂ rebreathing takes place mainly in single-limb circuits. Besides, the type of mask and expiratory port,^{23,33,34,36–38} and the level of EPAP used,^{21,34} end-tidal CO₂ concentration (EtCO₂), RR, tidal volume (Vt), were also the factors influencing CO₂ rebreathing.³⁵ However, the increasing level of EPAP was not as important as fixed-resistance exhalation devices since the leak flow rate of PEV was greater at ~ 4 –5 cmH₂O. During exercise, with the use of single-limb circuit with a PEV and nonvented mask, with the increasing Vt, RR, and EtCO₂, these could predispose patients to CO₂ rebreathing.

However, in this study, three of the COPD patients with their FEV₁ of 0.49, 0.52, and 0.61 L failed the curve fitness (adjusted $R^2 < 0.05$; Figure 3B), suggesting that there was no CO₂ rebreathing. As their FEV₁ (the maximum amount of air a person can expel in 1 s of forceful exhalation) were lower or within the inflection point (0.60–0.73 L/s), this in some extent supports our results. To ensure that no exhaled gas remains in the tubing at the end of expiration, the Vte/Te has to be lower than the intentional leak obtained through PEV (0.39–0.41 L/s) during expiration. Therefore, in some pulmonary rehabilitation programs, with the setting of pressure support similar to our study, with the increasing Vte/Te, it may not be suitable for patients whose FEV₁ exceeds 0.73 L to be included; it might be indicated as a reference value for patient inclusion in pulmonary rehabilitation programs with similar study setting.

This study has some limitations which need to be addressed. On the one hand, a limitation of this study is its small number of study patients. However, in this study, we have compared a large number of individual breaths for each respective subject. The comparison of individual breaths, rather than for example patients, is appropriate since the amount of rebreathing may depend on numerous factors, such as Vt, and timing of the respiratory cycle (RR and inspiratory duty cycle). Most of these exhibited large variations (in the same patient) on a breath-by-breath basis during spontaneous breathing with pressure support.

On the other hand, a nonlinear curve fit was applied to the scatter plot, CO₂ rebreathing inflection point was determined based on the nonlinear curve fit, and it was an indirect and rough estimation. R^2 is a number that indicates how well data fits a curve. In practice, an adjusted R^2 was usually close to 1 if the curve perfectly fitted the data and close to 0 when the curve did not fit the data at all, so the choice of 0.8 of R^2 was not critical. However, with the increase of ventilatory requirement, expiratory tidal volume, elevated breathing frequency and Vte/Te, tidal FiCO₂ increased significantly,

indicating that obvious CO₂ rebreathing existed in the single-limb circuit.

Since CO₂ rebreathing increased respiratory motor output, ventilation and work of breathing, reducing the efficiency of NIV to assist exercise,^{24,25} the current authors would suggest that the present findings would help design future studies on NIV-assisted exercise in COPD patients. First, our group previously found that CO₂ rebreathing could be minimized in COPD patients treated with NIV with the path of exhalation connected to the side hole on the mask at rest. In order to avoid CO₂ rebreathing, maybe such a setup modification could be used during exercise.²³ Second, an NRV applied on the single-limb during exercise will also be worth testing in future study. Third, use of double-limb ventilatory circuit other than the PEV to prevent CO₂ rebreathing should be considered during BiPAP ventilatory assistance.

Conclusion

Our results indicated that ventilatory assistance delivered in BiPAP mode with PS setting of 10 cmH₂O (IPAP:EPAP 14:4 cmH₂O) with single-limb tubing with PEV during exercise could produce significant CO₂ rebreathing. CO₂ rebreathing should be paid attention to in the pulmonary rehabilitation exercise programs that deliver bi-level pressure support ventilation with a single-limb circuit with PEV.

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Disclosure

The authors report no conflicts of interest in this work.

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