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ORIGINAL ARTICLE

Spontaneous breathing of heliox using a semi-closed circuit: A bench study

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ABSTRACT

Introduction: *The use of helium-oxygen mixture (heliox) for ventilation has an advantage in patients with obstruction of the airways. The physical properties of helium enable an easier gas flow through the airways; this enables easier breathing for the patient when compared to standard ventilation of air. A high cost of heliox falls within the factors that limit the use of heliox in clinical practice. At present, heliox is administered by use of an open circuit. The aim of this study is to propose a way of heliox administration that reduces heliox consumption but does not affect the positive heliox effects upon the airway resistance.*

Methods: *To minimize consumption of heliox, a semi-closed circuit has been designed. The circuit is a modification of an anesthetic circuit composed of parts with the lowest possible resistances. As any circuit has its own resistance, the evaluation of its possible negative effect upon the work of breathing of patients with exacerbation of chronic obstructive pulmonary disease (COPD) has been conducted.*

Results: *A semi-closed circuit for heliox administration has been constructed and evaluated. The intrinsic resistance of both the inspiratory and expiratory limbs of the circuit is less than 140 Pa·s/l. This resistance does not represent a significant workload for a patient with COPD exacerbation whose airway resistance is 10 to 20 fold higher.*

Conclusions: *The designed semi-closed circuit offers a potential benefit of heliox in patients with COPD exacerbation.*

KEY WORDS: *Heliox, COPD, Semi-closed circuit, Airway resistance, Respiratory system*

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INTRODUCTION

Heliox is a combination of two gases, helium (He) and oxygen (O_2). Helium is an odorless, tasteless, non-explosive, non-combustible inert gas that has no pharmacological effect at atmospheric pressure. The reason for using heliox is based on the principle that nitrogen (N_2) in inspired air is replaced with helium that has a significantly lower density. The physical properties of helium enable an easier gas flow through the airways; this enables easier breathing for the patient when compared to standard ventilation of air. Heliox reduces airway resistance and work of breathing in patients with airflow limitation (1-3). These effects of heliox are beneficial in patients with severe chronic obstructive pulmonary disease (COPD).

The main goal of the heliox administration is to avoid endotracheal intubation and invasive ventilation in patients with COPD exacerbation. Intubation and mechanical ventilation

may cause further damage to the lungs, inflammatory changes, and may increase the cost of medical care (3, 4). Heliox does not act as a bronchodilator; it should be used only for overcoming the critical period of respiratory insufficiency until the other therapy takes effect.
A high cost of heliox is one of the noticeable factors limiting the use of heliox in clinical practice (5). At present, heliox is administered by an open circuit. A major disadvantage of this method is a high consumption of heliox, because fresh gas flow should be approximately 2 or 3 times higher (15-22 l/min) than the minute ventilation of a patient. For minimization of heliox consumption, a semi-closed rebreathing circuit might be a suitable solution.
A semi-closed system comprises many components that have their own flow resistances. The use of this circuit causes an increase in work of breathing (referred to as imposed work of breathing) for a patient compared to a standard way of heliox administration using an open circuit. Imposed work of breathing loads the patient during spontaneous breathing (6, 7) and it may also deteriorate the desired positive effect of heliox. These facts should be considered when assembling a heliox semi-closed circuit. Components with the lowest possible airflow resistances should be selected in order to minimize the imposed work of breathing.
The aim of the study is to design and test a semi-closed rebreathing circuit for heliox application that does not significantly increase work of breathing in spontaneously breathing patients with COPD exacerbation.

MATERIALS AND METHODS

The construction of the heliox semi-closed circuit consisted of two phases. In the first phase, airflow resistances of various components manufactured by different producers were measured in order to select components with the lowest values of airflow resistance. In the second phase, the semi-closed circuit was assembled, optimized, and properly tested.
Flow resistances of separate components (breathing circuit tubes, bacterial filters, CO_2 absorbers, inhalation and exhalation one-way valves, airflow sensors for monitoring of ventilation, and humidifiers) were measured in a laboratory. The measured components were as follows: 5 breathing circuit tubes (length of 140 cm, corrugated 19 mm id, Intersurgical, Berkshire, UK; Evita, length of 120 cm, 15 mm id, Siemens, Prague, Czech Republic; length of 195 cm and of 120 cm, corrugated 20 mm id, Intersurgical, Berkshire, UK; and Avea, length of 195 cm, corrugated, Viasys Healthcare, CA, USA), 7 bacterial filters (Clear-Guard 3, Intersurgical, Berkshire, UK; Servo DUO Guard, MAQUET GmbH & Co. KG, Rastatt, Germany; Fisher&Pykel Healthcare, Schorndorf, Germany; HepaShield, Flexicare Medical., Mid Glamorgan, UK; Hygrovent S, Medisize, Trhové Sviny, Czech Republic), 2 carbon dioxide absorbers (Chirana, Stará Turá, Slovak Republic), 3 inhalation and exhalation one-way valves (Chirana, Stará Turá, Slovak Republic), 3 airflow sensors for monitoring of ventilation (Ergo 3, Medset Medizintechnik, Hamburg, Germany; SpiroQuant H, ENVITEC-Wismar, Wismar, Germany; Disposable D-lite sensor, GE Healthcare, Munich, Germany) and 2 chambers of humidifiers with tubing and heated wires (MR210/MR250; Fisher & Pykel Healthcare, Schorndorf, Germany).
Flow resistances were measured at flow rates of 30 and 60 l/min as a pressure drop across the individual components by a differential pressure meter Testo 525 (Testo, Lenzkirch, Germany). The resistance values were measured for both dry air and dry heliox 79:21 (a mixture comprising 79% of helium and 21% of oxygen) at a temperature of 37°C. Either compressed air of medicinal quality or heliox from 50 L cylinders pressurized at 15 MPa (Messer Technogas, Prague, Czech Republic) was used for the measurement. A constant gas flow was generated by a mass flow controller (MKS Instruments Deutschland, Munich, Germany). As the reading of the mass flow controller depends on the physical properties of the gas, the controller correction factor was changed correspondingly when heliox was used instead of air according to the mass flow controller documentation and recommendations published by Corcoran (8). An independent measurement of flow rates either for air or for heliox was permanently conducted using a volume flow meter (Chirana Prema, Stará Turá, Slovak Republic), the measurement of which is independent of the gas density and viscosity.
Finally, the whole inspiratory limb (comprising a complete inspiratory part of the semi-closed circuit with an absorber of carbon dioxide) and expiratory limb (comprising the complete expiratory part of the semi-closed circuit) were tested. In order to measure resistance of the inspiratory limb, the constant gas flow source was connected to the circuit at the point of a bag connector (position "A" in Fig. 1) and the gas was released from the circuit at the point of the facial mask connector (position "B" in Fig. 1). In order to measure resistance of the expiratory limb, the

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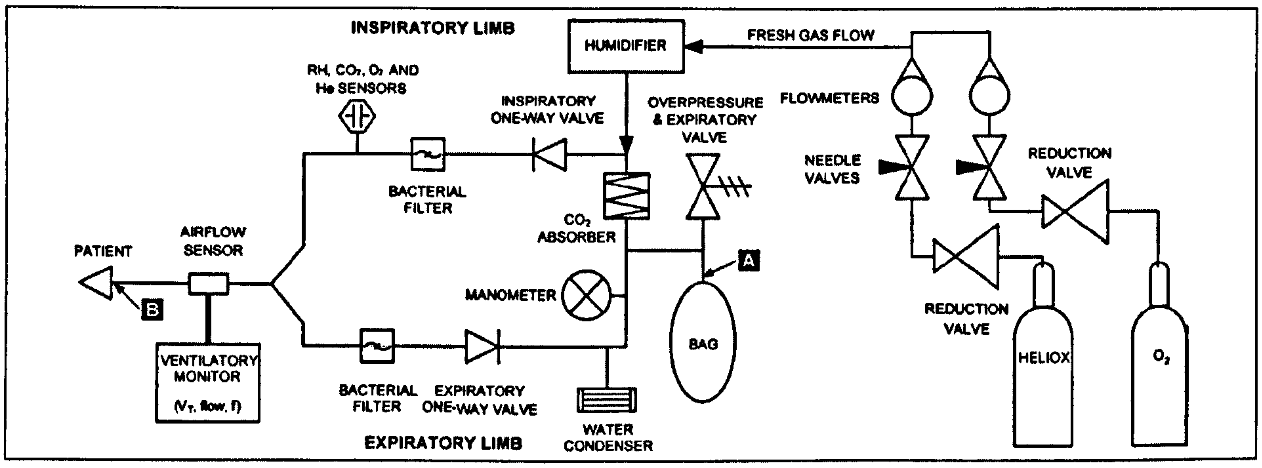

Fig. 1 - *Scheme of the semi-closed circuit for heliox administration.*

source of constant gas flow was connected to the circuit at the point of the facial mask connector (position "B") and was released from the circuit at the point of the bag connector (position "A") when the bag was removed. A pressure drop developed between positions "A" and "B" was divided by the flow rate used for the measurement in order to obtain resistance of the inspiratory limb and a pressure difference between positions "B" and "A" was used for calculation of the expiratory limb resistance. These resistance values represent the overall resistive loads for a patient during the spontaneous breathing by using the semi-closed circuit.

RESULTS

Considerable differences in resistance between the examined individual components of the same kind were recorded. The measured resistances are presented in Table I. From the measured components, those with the lowest airflow resistances were selected for assembling of the semi-closed circuit.

As chambers of humidifiers with the corresponding tubing represent a significant flow resistance, the humidifier was placed outside the loop of the semi-closed circuit; the humidifier is connected between the source of the fresh gas and the semi-closed circuit loop. The humidifier heats and moisturizes the fresh gas before it enters the circuit loop. The overall scheme of the semi-closed circuit is presented in Figure 1.

The measured resistances of the both limbs are presented in Table II. The table also demonstrates flow resistance characteristics of two additional components. The first component is an airflow sensor that is normally not present in the circuit but may be required for measurement of tidal volumes and minute ventilation, especially during research clinical trials. The second component is a bacterial filter with the lowest resistance from all the tested bacterial filters which may be employed depending on the way of sterilization of the equipment.

DISCUSSION

The most important results presented in Table II are the resistance of the complete inspiratory and expiratory limb of the assembled semi-closed circuit when heliox is used. This is the condition under which the circuit is intended to be utilized in clinical practice. The resistances for both the limbs at both flow rates of heliox do not exceed 140 Pa·s/l. This is the maximum value that the semi-closed circuit would add to the patient's respiratory system resistance and therefore would induce imposed work of breathing that a patient should overcome. This value of the equipment resistance should be negligible when compared with the intrinsic airway resistance in patients with COPD exacerbation. Furthermore, the circuit resistance should be much smaller than the improvement of the respiratory system airway resistance induced by administration of heliox instead of air. Only under these conditions the positive effect of heliox on

TABLE I - RESISTANCES OF THE EVALUATED COMPONENTS (OVERALL RESULTS) MEASURED FOR AIR AND HELIOX AT TWO FLOW RATES OF 30 AND 60 L/MIN

	Range of Flow Resistance R (Pa·s/l)			
	Air		Heliox	
Component type	Q = 30 l/min	Q = 60 l/min	Q = 30 l/min	Q = 60 l/min
Circuit tubes	40–235	55–411	32–102	37–156
Airflow sensors	60–155	57–178	34–92	32–88
Bacterial filters	116–392	127–438	100–342	108–359

TABLE II - FLOW RESISTANCES OF THE INSPIRATORY AND EXPIRATORY LIMBS OF THE SEMI-CLOSED CIRCUIT AND RESISTANCES OF THE SELECTED AIRFLOW SENSOR AND BACTERIAL FILTER

		Flow Resistance R (Pa·s/l)			
		Air		Heliox	
Component	Characteristics	Q = 30 l/min	Q = 60 l/min	Q = 30 l/min	Q = 60 l/min
Inspiratory Limb	Complete semi-closed circuit + CO_2 absorber	200	212	138	130
Expiratory Limb	Complete semi-closed circuit	176	178	122	105
Airflow Sensor	Ergo 3, Medset Medizintechnik GmbH, Hamburg, Germany	60	57	34	32
Bacterial Filter	Servo DUO Guard, MAQUET GmbH & Co. KG, Rastatt, Germany	116	127	100	108

reduction of the flow resistance is preserved and is not overridden by the imposed resistance of the semi-closed circuit. Just a few studies (2, 9, 10) report the measured airway resistances of the respiratory system in patients suffering from COPD exacerbation both for air/oxygen mixture and for heliox. Furthermore, different methods of resistance assessment are often used. Results may vary significantly when spontaneous breathing or mechanical ventilation is used. Comparability of the measured data is further complicated due to different methods of evaluating resistance. Examples of this are when the total respiratory system resistances are measured; or only airway resistance is measured, with or without subtraction of the endotracheal tube resistance. Several other conditions may also influence the presented values. The average resistances of the respiratory system in COPD exacerbation patients involved in these studies were in the range of 1.5 kPa·s/l to 2.9 kPa·s/l. An improvement of the airway resistance by 0.5 kPa·s/l to 1.0 kPa·s/l is reported. When comparing the maximum inspiratory or expiratory limb resistances of the assembled semi-closed circuit, these values are always less than 10% of the measured resistances in the above-mentioned studies. Furthermore, the circuit resistance is substantially lower than the respiratory system resistance reduction when heliox is used instead of air/oxygen mixture. As a consequence, administration of heliox using the semi-closed circuit should preserve the positive heliox effect on the respiratory system resistance reduction whereas the consumption of heliox is minimized. The resistance of the semi-closed circuit, even though it has been minimized, represents a disadvantage of the tested method of heliox administration. A possible solution may be usage of an active heliox administration system similar to the Demand Flow System, when the device registers the spontaneous breathing activity of a patient and actively changes gas flow and pressure in the ventilator circuit accordingly (11-13). The Demand Flow System reduces work of breathing significantly and facilitates spontaneous breathing of a patient. The obstacles to use of such a system are the complexity of the Demand Flow System and the fact that the device is still under development.

CONCLUSIONS

The designed semi-closed circuit for spontaneous breathing of heliox offers an alternative way of heliox administration in patients suffering from COPD exacerbation that may reduce consumptions of heliox. However, its efficiency should be confirmed by a clinical trial.

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