TECHNICAL SOLUTIONS OF SEMI-CLOSED CIRCUITS FOR HELIOX ADMINISTRATION IN SPONTANEOUSLY BREATHING PATIENTS WITH SEVERE AIRWAY OBSTRUCTION

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Abstract

A semi-closed circuit represents a cost effective alternative of heliox application in patients with severe airway obstruction. A semi-closed circuit has its intrinsic resistance that compromises the positive effect of heliox in the obstructed airways. The resistance may be reduced and depends on the design of the circuit. The article proposes two alternative configurations of semi-closed circuits for heliox application differing in their resistive properties and complexity of their construction.

Keywords

heliox, helium, respiratory care, semi-close circuit, COPD, airway resistance, work of breathing

Introduction

The term heliox refers to a mixture of helium and oxygen, in which the original fraction of nitrogen in the air is replaced with helium. The first use of helium in treatment of upper airway obstruction and asthma exacerbation was described by Barach in 1934. Physical properties of helium are different from those of nitrogen or air. The most significant property which makes heliox attractive for medical use is its extremely low density compared to air [1]. The density of helium is approximately one seventh of that of air [2]. Lower density reduces turbulent flow in the airways. Therefore, heliox reduces airway resistance and work of breathing in patients with airflow limitation [3]. This airflow limitation due to the narrowed airways occurs in chronic obstructive pulmonary disease (COPD), asthma bronchiale, epiglottitis, laryngitis, tracheitis, bronchiolitis, and other respiratory diseases.

COPD is a serious lung disease, ranked as the fourth leading cause of death worldwide. World Health Organization predicts that COPD will become the third leading cause of death by 2030. It is a treatable lung disease, which is preventable. Its pulmonary component is characterized by a limited bronchial airflow (bronchial obstruction), which is not fully reversible. COPD often develops in long-term smokers. Acute exacerbation of COPD is a frequent reason for hospital admission, e.g. to the intensive care unit.

The aim of heliox therapy is to support respiration in order to prevent a failure of basic vital functions. The treatment includes invasive and non-invasive methods. In severe exacerbations with respiratory insufficiency the spontaneous ventilation often fails and mechanical ventilation should be initiated.

Non-invasive heliox administration in patients with severe airway obstruction significantly reduces the flow resistance in the airways. Heliox, therefore, improves a patient's comfort. This may help to postpone intubation and avoid invasive mechanical ventilation.

Unfortunately, clinical usage of heliox is limited. Its high price and enormous consumption when administered by a standard way using an open circuit belong to the significant limiting factors. In spontaneously breathing patients, heliox is administered using an open circuit via a facemask

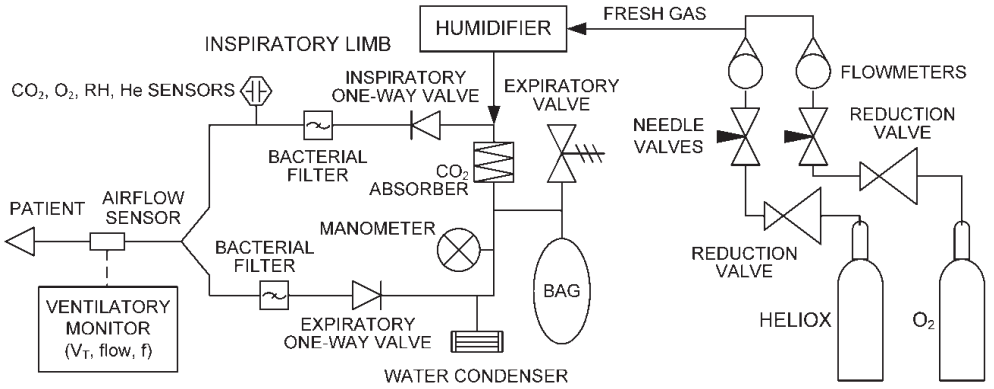

Fig. 1: Semi-closed circuit for heliox administration [5].

connected to a reservoir bag with a sufficient inflow to keep the bag inflated [4].

The newly developed solution of semi-closed circuit for heliox administration has been introduced [5]. This semi-closed circuit works as a re-breather that significantly reduces the consumption of helium and offers an affordable way of relieving symptoms of severe airway obstruction with a possibility of avoiding intubation and invasive mechanical ventilation. On the other hand, the semi-closed circuit consists of additional components that increase the flow resistance [5, 6].

The aim of this study is to propose alternative solutions of semi-closed circuits for heliox administration in spontaneously breathing patients that minimize flow resistance to preserve the beneficial effect of heliox during treatment of severe airway obstruction.

Semi-closed circuits for heliox administration

Semi-closed circuit

The semi-closed circuit [5] comprises inspiratory and expiratory limbs. Fresh gas flow is moistened with a humidifier and enters the inspiratory limb through an inspiratory one-way valve. Patient breathes through a facial mask that is attached to the corrugated tube connected to inspiratory and expiratory bacterial filters. Bacterial filters are used to eliminate infection. Expired gas flows through a one-way expiratory valve to the expiratory bag. An expiratory valve (APL valve, Adjustable Pressure Limiting valve) attached to the bag lets the excessive gas out of the circuit if an overpressure occurs. The gravitational one-way

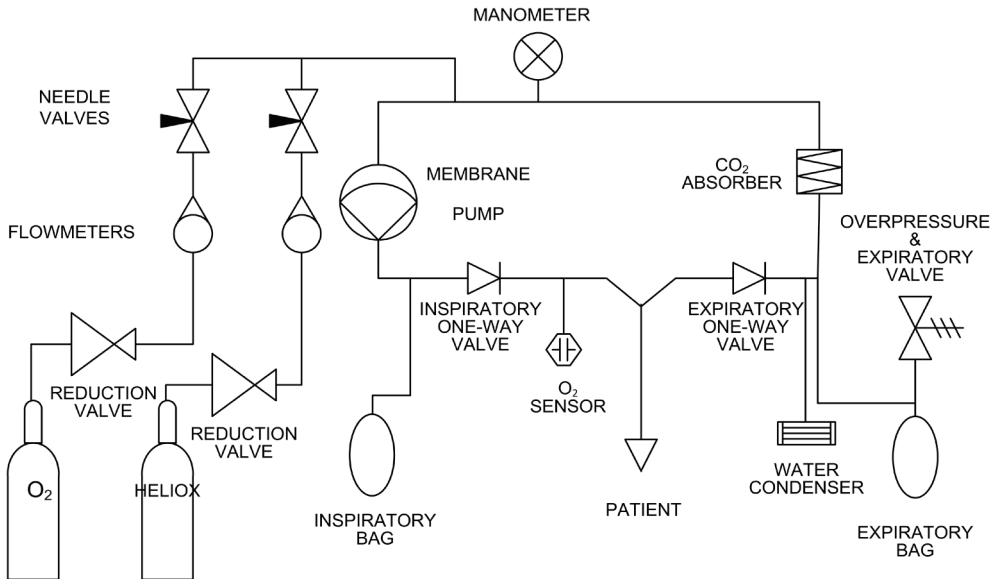

Fig. 2: Two bags system with two one-way valves and a gas pump.

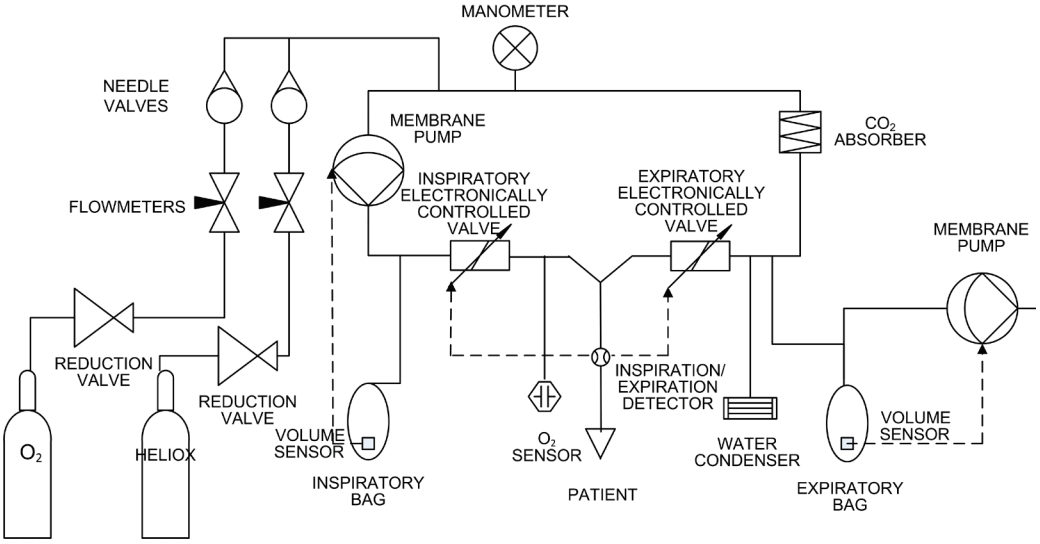

Fig. 3: Two bags system with electronically controlled on/off valves.

inspiratory and expiratory valves assure that the patient does not inhale the already expired gas. CO_2 in the expired gas is absorbed in a CO_2 absorber. A water condenser is put close to the expiratory valve to collect condensed water from the exhaled gas (Figure 1).

This semi-closed circuit works as a re-breather and helium consumption is lower compared to the standard open system. The helium consumption can be less than 1 L/min but it is mainly limited by a gas leak under the facial mask and by a gas leak from the circuit. Unlike the open system, added components of the semi-closed system increase airflow resistance [5, 6], that requires increased work of breathing for a patient. In order to maintain the positive effect of helium at low consumption, the two novel systems of semi-closed circuits have been proposed.

Two bags system with two one-way valves and a gas pump

The first proposed system consists of two standard one-way valves and two breathing bags. In order to refill the inspiratory bag, a membrane pump has been added into the circuit. The pump either works continuously with the flow rate equal to the patient's minute ventilation, or the pump is activated intermittently when the volume of gas in the inspiratory bag decreases what may be indicated by a volume sensor placed inside the inspiratory bag. The scheme of this system is presented in Figure 2.

Two bags system with electronically controlled on/off valves

The scheme of the second proposed system is presented in Figure 3. The circuit consists of two breathing bags and two electronically controlled valves. The system is equipped with a detector which is able to detect inspiration and expiration of the patient similarly as a pressure trigger during mechanical ventilation or a demand flow system [7, 8]. A signal from this detector controls the valves so that the inspiratory valve is open during inspiration and expiratory valve is open during expiration. This assembly assures a one-directional flow through the circuit.

The system comprises two pumps. The first pump is responsible for inflating the inspiratory bag, the second one should release the excessive amount of gas when the expiratory bag is full. Both the pumps are controlled by volume sensors situated in the inspiratory and expiratory bags.

Discussion

The advantage of the first proposed configuration (Two bags system with two one-way valves) is that the patient doesn't need to overcome the resistance of the CO_2 absorber and adjacent parts of the circuit tubes, because the gas is forced to flow through these components by a membrane pump. The main disadvantages of this solution are the presence of the one-way valves that have quite significant airflow resistance and the breathing bags are inconveniently placed in a vicinity of the patient.

The advantage of the second proposed solution (Two-bags system with electronically controlled on/off valves) is that the mechanical one-way valves are replaced with electronically controlled on/off valves. Due to their construction, these electronic valves can

have much lower airway resistance in comparison with the original mechanical one-way valves. Disadvantage of this system is a relative complexity of the system, when the special control circuits and appropriate sensors are needed. In order to minimize the airflow resistance, the bags should be placed in a vicinity of the patent, which may be inconvenient.

In order to evaluate and compare the proposed systems, the systems should be constructed and their resistive properties should be characterized in a future study.

Conclusion

A renewed interest in low-density helium-oxygen mixture in respiratory care seems to be beneficial for patients suffering from severe airway obstruction. A semi-closed circuit for heliox administration can offer an affordable way of treatment for spontaneously breathing patients. However, a semi-closed system bears an additional work of breathing. Possibilities of cheaper and low resistance ways of heliox administration have been analyzed. Two designs of a semi-closed circuit for heliox administration have been proposed. Testing of the designed circuits in the laboratory and clinical setup is necessary for selecting the best solution of ventilatory support for spontaneously breathing patients with severe airway obstruction.

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