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Use of Heliox during Spontaneous Ventilation: Model Study

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***Abstract*—**The study deals with the modelling of the gas flow during heliox therapy. A special model has been developed to study the effect of the helium upon the gas flow in the airways during the spontaneous breathing. Lower density of helium compared with air decreases the Reynolds number and it allows improving the flow during the spontaneous breathing. In the cases, where the flow becomes turbulent while the patient inspires air the flow is still laminar when the patient inspires heliox. The use of heliox decreases the work of breathing and improves ventilation. It allows in some cases to prevent the intubation of the patients.

***Keywords*—**Gas flow, heliox, Reynolds number, turbulent flow.

I. Introduction

LOT of problems may result in respiratory insufficiency of people suffering by respiratory problems. These patients require use of artificial lung ventilation or different supportive ventilatory techniques that will provide sufficient amount of oxygen to the patient. Despite the use of new ventilatory techniques in the respiratory care, there still remains a lot of patients that have no or small benefit from the use of artificial lung ventilation. Lower density of heliox contrary to air decreases the work of breathing and improves the patient's oxygenation. The usage of heliox during spontaneous breathing could prevent the patients from intubation.

It also optimizes the spontaneous breathing of the patients that suffers for example by asthma [1].

II. Methods

The aim of this study is to simulate the effect of the use of heliox as a ventilatory mixture using a model of the respiratory system implemented in MATLAB [2]. Heliox is a gas mixture of oxygen and helium. If it is used in the respiratory care it is mixed often in 80:20 (70:30) ratio. It means that there is 80 (70) % of helium and 20 (30) % of oxygen in the mixture. Helium is an inert gas. It does not react with the human tissue; therefore the helium has no adverse effects upon the patient even when it is used for long periods [3]. The main advantage of the helium is lower density contrary to air. Helium has also low molecular weight and high rate of diffusion. It suggests that use of helium in the respiratory care can reduce the work of breathing and improve aerosol delivery in the respiratory system [3]. Gas properties are shown in Table I.

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TABLE I
Gas Properties

Gas	Density (kg.m^{-3})	Viscosity (µ Poise)
O_2	1,429	211,4
He	0,179	201,8
80 % N_2, 20 % O_2	1,293	188,5
80 % He, 20 % O_2	0,429	203,6
70 % He, 30 % O_2	0,554	204,7

Heliox has a substantially smaller density contrary to air. Density and viscosity of the fluid mainly determines the characteristics of the flow. The laminar flow is viscosity-dependent and density-independent. The flow during laminar flow is described by Hagen-Poiseuille equation:

$$\dot{V} = \frac{\pi.r^4.\Delta P}{8.\eta.l}, \tag{1}$$

where r is a diameter of the tube, ΔP is the pressure gradient, η is dynamic viscosity of the fluid and l is the length of the tube.

When the turbulent flow occurs the flow id described by equation:

$$\dot{V}^2 = \frac{4\pi.r^5\Delta P}{\rho.l}, \tag{2}$$

where ρ is a density of fluid.

It is evident that flow is smaller during the turbulent flow. The character of the flow is determined by the Reynolds number and it is computed according to the following equation:

$$\mathrm{Re} = \frac{\rho.v.d}{\eta}, \tag{3}$$

where v is velocity and d is diameter of the tube (airway) and η is dynamic viscosity.

The flow is laminar when the Reynolds number is smaller than 2000 approximately. The gas flow during turbulent flow is less efficient, therefore the effort of the staff is to maintain the laminar flow in the respiratory care. The Reynolds number is much smaller with helium contrary to air or oxygen. In the cases, where the air flow becomes turbulent the heliox flow still remains laminar.

The gas flow during an orifice is described by equation (4):

$$\dot{V} = \left(\frac{2.\Delta P}{\rho} \right)^{0.5}. \tag{4}$$

The flow through an orifice is density-dependent. It means that heliox has theoretical assumptions to flow better through the orifice when compared with air flow or oxygen flow.

The flow through potentially obstructed airway is described by the Bernoulli equation:

$$P_1 - P_2 = \frac{1}{2} \rho.(v_2^{\ 2} - v_1^{\ 2}). \tag{5}$$

The gas flow velocity becomes higher in the obstructed airway and the flow may become turbulent. This dependency is also density dependent through Reynolds number and the gas flow will be more effective with heliox compared with air. Higher gas flow velocities are compensated by lower density of heliox.

The heliox has a lower density contrary to air or oxygen and presented equations show that heliox should have better flow properties.

Heliox is used in the respiratory care in many cases as a mixture of 30 % of oxygen and 70 % of helium (heliox 70:30) or 20 % of oxygen and 80 % of helium (heliox 80:20). The use of heliox is studied in the mathematical model of the respiratory system that was developed to study the gas flow in the airways [2]. The aim of the study is to support the theory that heliox can optimize the spontaneous breathing of the patient during respiratory disease.

Geometrical proportions of Weibel's morphologic model of the respiratory system were used to design the model of the airways according to the anatomical structure of the respiratory system [4]. The effect of heliox physical properties upon the gas flow in the airways is studied using the mathematical model of the airways.

III. Results

The study is designed for adult patient with following breathing parameters: tidal volume V_t = 0,5 l, breathing frequency f = 15/min, time of inspiration t_{ins} = 5/3 s.

Reynolds number for gas flow in airways was computed for air and heliox mixtures with ratio 80:20, 70:30 and 60:40. The values of Reynolds number in first five generations of the bronchial tree are shown in Fig. 1.

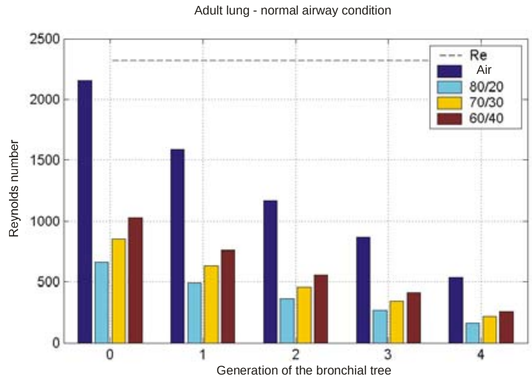

Fig. 1 The Reynolds number in airways for heliox and air for normal condition of airways

The diameter of the airways was twice decreased in generations 1 and 2 to model the obstruction of the airways. Tidal volume and breathing frequency remain the same. The values of Reynolds number are depicted in Fig. 2.

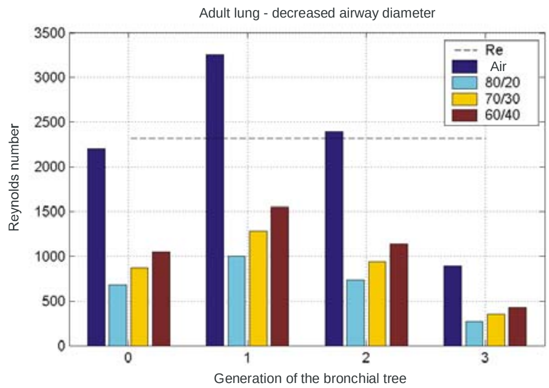

Fig. 2 The Reynolds number in airways for heliox and air during obstruction of the airways

IV. Discussion

The results of conducted simulations show that gas flow is laminar in the airways during normal condition of the airways for both: air and heliox. The Reynolds number is lower than 1500 for air. The Reynolds number is significantly lower when heliox is used as the respiratory mixture. The Reynolds number decreases with the generation of the bronchial tree as the velocity of the gas flow become lower.

The diameter of the airway was 2x decreased for simulation of the obstructed airways. Reynolds number is in trachea almost 3000 during breathing air and it suggests that the gas flow is turbulent in the trachea. It means that gas flow is less efficient and smaller amount of gas enters the lungs. The Reynolds number is lower when simulating the use of heliox and the gas flow remains laminar contrary to air. The gas flow is more efficient with heliox when the airways are obstructed.

V. Conclusion

The conducted simulations show that Reynolds number is significantly lower during heliox therapy. It suggests that heliox can be used to improve the gas flow during spontaneous ventilation and maintain sufficient oxygenation without an intubation of the patient. The clinical study will be made to confirm these results.

Acknowledgment

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