Mathematical modeling of extracorporeal CO2 removal

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***Abstract*—Extracorporeal CO_2 removal devices ($ECCO_2R$) can be used in clinics to decarboxylate blood externally for patients suffering from pulmonary insufficiencies like acute respiratory distress syndrome. In this work, a model of the respiratory system coupled with such a device is proposed to analyze the decrease of CO_2 partial pressure in blood as a function of blood flow through the device. This model provides a mathematical tool which could help clinicians to choose the optimal settings of $ECCO_2R$.**

I. Introduction

Acute respiratory distress syndrome (ARDS) is still life threatening despite new strategies in mechanical ventilations [1]. Usually patients are ventilated with low tidal volume, low airway pressure and high content in O_2. Such ventilation can induce a hypercapnic acidosis, which is very deleterious for the global physiology. Consequently, extracorporeal CO_2 removal devices ($ECCO_2R$) are used to control the CO_2 partial pressure (pCO_2) in blood. The higher the flow in the device, the faster the decrease in pCO_2 but to increase the flow, large cannulas are needed, which could result in an increased risk of haemorrhage and infections. To optimize the use of $ECCO_2R$, a mathematical model was developed. Both the respiratory system and the $ECCO_2R$ were described and the behavior of the coupled system was studied in terms of the blood flow crossing the machine.

II. Methods

Several mathematical models of the respiratory system exist, with different purposes and different levels of details. Since a real-time use of the model in a clinical environment is sought, a simple model derived from the works of Batzel *et al*. [2] and Karbing *et al*. [3] was built for which a pulmonary shunt is taken into account in parallel to the lungs. The modelling of the $ECCO_2R$ consists in adding a second "lung compartment", which is perfused by a fraction of the systemic blood flow extracted in the inferior vena cava and reinjected in the atrium, after crossing the device [4].

III. Validation

The validity of the model was tested by comparing its predictions with experimental data. The experiments were carried out on pigs, with the approval of the Ethics Committee of the Medical Faculty of the University of Liège (see Morimont *et al.* [5] for the detailed protocol). ARDS was induced in the animals and an extracorporeal CO2 removal device was used to decarboxylate the blood. Fig. 1 shows the good agreement that was obtained between the experimental and calculated time evolutions of pCO_2 and of pH in the arteries for a blood flow in the $ECCO_2R$ equal to 0.6 l/min.

IV. Results and Discussion

Our results are presented in Fig. 2, which shows the decrease of pCO_2 in terms of the flow crossing the $ECCO_2R$. These results correspond to the pig considered in Fig.1 but different blood flows through the extracorporeal device were simulated. As expected, the decrease is faster for large values of the flow. Our calculations can thus be considered as a first step towards an optimized clinical use of $ECCO_2R$.

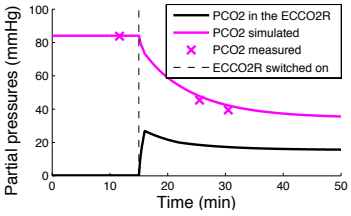

Figure 1. Comparison of experimental data vs. simulation

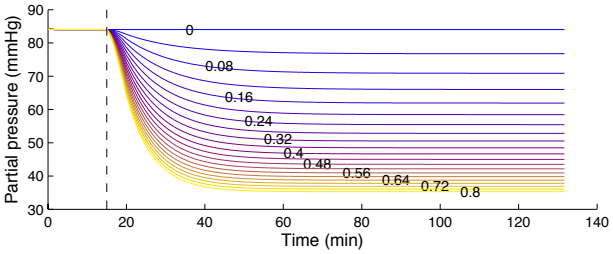

Figure 2. pCO_2 decrease in time. Labels on the curves give the blood flow (l/min) through $ECCO_2R$, which is switched on at *t =15 min*.

References

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*Research supported by the belgian F.R.S-FNRS.

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