The Role of Physiological Models in Critiquing Mechanical Ventilation Treatments

Tehrani, FT[1], Abbasi, S[2,3]

[1]Department of Electrical Engineering, California State University, Fullerton, 800 N. State College Boulevard, Fullerton, California 92831, USA; [2]University of Pennsylvania School of Medicine. Philadelphia, Pennsylvania, USA; [3]CHOP Newborn Care at Pennsylvania Hospital, 800 Spruce Street, Philadelphia, Pennsylvania 19107, USA

Introduction: Choosing the correct ventilatory parameters for ICU patients is an important clinical decision that needs to be made with care and sufficient knowledge about the patient's conditions as well as the features of today's advanced ventilators. Computerized decision support systems can be used as helpful tools in setting the ventilator parameters for ICU patients on mechanical ventilation. There have been many decision support systems developed by various researchers for this purpose over the past few decades [1, 2]. While decision support systems can be used by clinicians to choose the ventilatory parameters, a system based on a physiological model of the patient can provide further advice to clinicians by predicting the treatment outcome and critiquing their decisions. The present study was designed to examine the effectiveness of a model based critiquing system.

Methods: The system used to critique the ventilatory treatment options in this study is based on an earlier physiological model of the infant respiratory system [3]. That model consists of a continuous plant and a discrete controller. For the purpose of this study, the discrete controller of the model was replaced by a positive pressure mechanical ventilator providing pressure to the infant's airways and the inspiratory gas. A block diagram of this system is shown in Figure 1. As shown in this figure, the system includes lungs, body tissue and brain tissue. The lung volume is continuously time varying and the effect of shunt in the lung, changes in cardiac output, and the arterial transport delays are included in the model. The mass balance equations of these compartments are provided in Reference 3. The inspiratory gas is provided by a positive pressure mechanical ventilator to the lungs. The expansion of the lungs is controlled by the amount of pressure applied by the ventilator and the infant's lung mechanics. The inspiratory gas comes into contact with the alveolar tissue. The venous blood supplied to the lungs by the heart absorbs oxygen from the inspired gas and loses its carbon dioxide to it during inspiration. The gas is then exhaled and the oxygenated blood leaves the lungs but mixes with some venous blood due shunt in the lung before being pumped by the heart and delivered to the brain and the body tissues. A list of the internal parameters of this model and their default values are provided in Reference # 3.

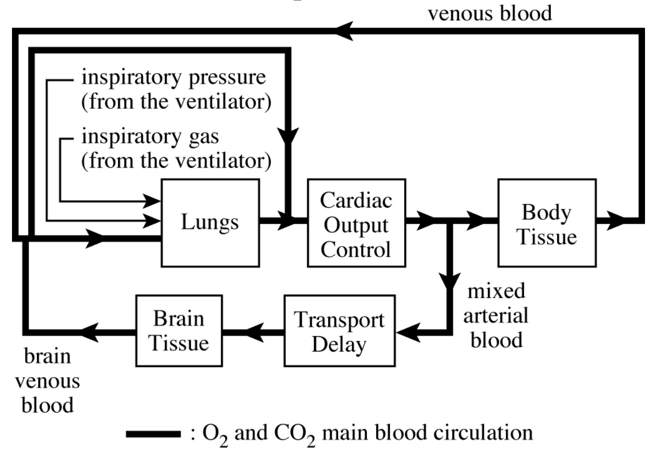

Figure 1. A block diagram of the model.

For the purpose of this study, the ventilatory and physiological data of an infant reported in a previous study [4] were used. In that study, a computerized system for mechanical ventilation called FLEX was used to determine the optimal ventilatory parameters of a group of infants. FLEX is a new system that can be used as a closed-loop controller as well as an open-loop decision support advisory system for mechanical ventilation. FLEX includes the features of a patented commercial ventilatory mode called Adaptive Support Ventilation (ASV) [5]. FLEX further includes many additional features for control of fraction of inspired oxygen (F_{IO2}), positive end-expiratory pressure (PEEP), minute ventilation, and weaning. More details of FLEX can be found in other references [4] and are not repeated here for brevity. The infant whose data is used in this study is infant #5 in Reference #4, who is a male one-day old infant of 2.5 Kg weight, with respiratory distress syndrome (RDS). The clinician's set of ventilator parameters as well as the recommended parameters by FLEX were input to the physiological model of Figure 1 in two separate simulation studies. The simulation results were used in a comparison between the two treatment options.

Results: The clinician's set of ventilatory parameters for the infant of this study resulted in a tidal volume of 5.7±2.7ml, and a breathing rate of 68±18 breaths/minute including an intermittent mandatory (IMV) rate of 35 breaths/minute. F_{IO2} was set at 21%, and PEEP was 5 cmH_2O. The respiratory airway resistance and respiratory dynamic compliance of this infant were measured at 143±60 cmH_2O/l/s, and 0.93±0.39 ml/cmH_2O respectively. The FLEX computerized system recommended a ventilation of 0.66 l/minute, a total respiratory rate of 45.5 breaths/minute including the IMV rate, an F_{IO2} of 21%, and a PEEP of 4.2 cmH_2O. Figures 2a and 2b show the simulation results of arterial partial pressures of CO_2 (P_{aCO2}), and O_2 (P_{aO2}) for this infant by using the clinician's set of parameters and the FLEX recommended parameters respectively.

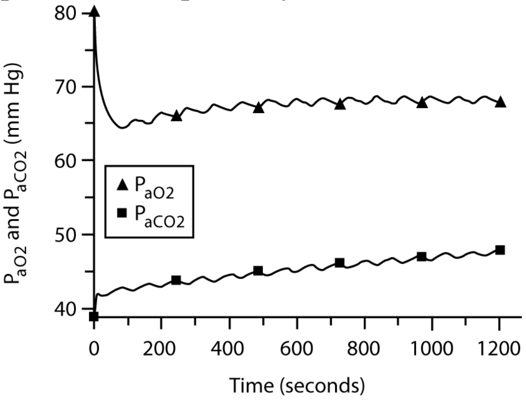

Figure 2a. Simulation results by using the clinician's set of ventilatory parameters for infant #5 in Reference #4.

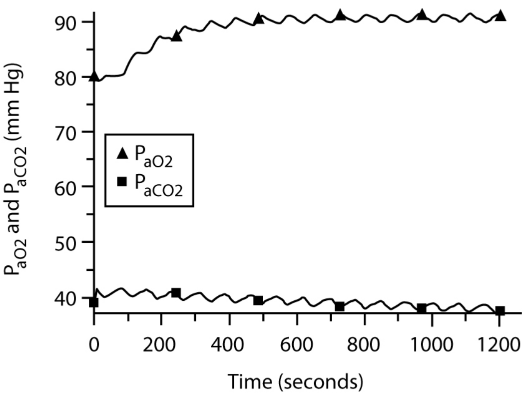

Figure 2b. Simulation results by using the ventilation parameters recommended by a computerized system called FLEX, for infant #5 in Reference #4.

Discussion: According to the simulation results of Figure 2a, the use of the clinician's set of parameters should result in hypercapnia with P_{aCO2} rising to about 47 mmHg and a decline in P_{aO2}. At the next round of evaluation in Reference #4, the end-tidal CO_2 pressure of this infant was measured at 43 mmHg, representing mild hypercapnia, and the arterial oxygen saturation of this infant was somewhat decreased. The results of Figure 2b predict that by using the FLEX recommended values, there would not be any hypercapnia or any reduction in P_{aO2}. These results show that by using the model based critiquing system, the clinician would have been able to get more information about the treatment outcomes and make a more informed choice between normocapnia and mild permissive hypercapnia for this infant. This example indicates that systems based on physiological models have the potential to be used as helpful tools in critiquing ventilatory treatment options.

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