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A New Decision Support System for Mechanical Ventilation

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Abstract- A decision support system has been developed for the treatment and management of patients on mechanical ventilation. The following criteria have been used in the design of the system; a) to regulate arterial blood gases within the normal range, b) to optimize ventilatory treatment in order to minimize the breathing work rate, and c) to reduce the weaning time from the ventilator. The system incorporates many safety features and can be used as an advisory tool as well as an informative source of patient data. Another application of the system is in automatic control of weaning.

Index Terms: mechanical ventilation, decision support systems, ventilator weaning

Introduction to Method

Mechanical ventilation is one of the most widely used methods of treatment, particularly in the intensive care and constant care hospital settings, for many different patient populations. Appropriate choice of ventilatory parameters and timely weaning from the ventilator are the key factors in determining the outcome of such a treatment. Despite the development of several commercially available closed-loop ventilatory techniques, most ventilators are still mainly open loop devices whose outputs are set by clinicians. Effective and well designed decision support systems can be used as valuable tools in setting the output parameters of today's advanced mechanical ventilators. Various decision support systems have been developed for mechanical ventilation in recent years. There are rule-based systems that are designed for treatment of ARDS patients only [1, 2]. Also, there are systems that are developed for specific ventilation modes such as pressure support ventilation and are designed as rule-based weaning expert and control systems [3, 4]. In addition, some other rule-based systems are available that use Fuzzy logic design to control patients' weaning [5]. More recently, another expert system for setting mechanical ventilation variables was introduced that uses physiological models [6]. Although the mathematical models and procedures used in that system have not been clearly specified, but such a model-based system is bound to require a large number of physiological parameters, many of those not easily measurable or available at bedside.

Unlike the previous rule-based systems, the system introduced in this article derives most of its rules on the basis of the conditions and bodily requirements of individual patients, and therefore, does not apply the same rules to all patients. The system presented here has been developed to provide decision support in a variety of ventilatory modes and to a wide range of respiratory patients. The system does not use any physiological model of oxygen and carbon dioxide transport and therefore does not require a long range of physiological parameters that would have otherwise been needed. However, many formulas and procedures of the system are based on physiological hypotheses that have been widely tested successfully in the past.

Closed-loop systems have been developed to automatically regulate ventilatory control and to maintain the patient's arterial blood gases within the normal range [7-9]. Besides expediting the weaning procedure, one of the main objectives of the proposed decision support system in this paper has been to help regulate the patient's blood gases in the normal range. The system is designed to help prevent hypocapnia, hypercapnia, hypoxemia, hyperoxemia, and oxygen toxicity. It provides advice to the clinician to regulate the patient's oxygen level while preventing high levels of inspired oxygen concentration (FIO) and unnecessary high levels of positive end-expiratory pressure (PEEP). The system is also designed to reduce and minimize the breathing work rate and to reduce the ventilator weaning time. It provides advice to the clinician regarding the status of the patient and whether the weaning procedure should be started, continued, or stopped. The output of the system can also be used for closed-loop control of weaning. By reducing the time that the patient is sustained by the ventilator and expediting weaning from the ventilator, the system can be used as a helpful tool in reducing the mortality and morbidity rates associated with prolonged mechanical ventilation.

Overview of the Decision Support System

In addition to providing treatment advice, the decision support system which is called FLEX (for ventilatory treatment) is designed to keep the records of different patients and to provide accumulated patient data over time to the clinician. Every time the system is started, the clinician in charge can create a new file for a new patient or follow up on an existing patient or view patient's data. Figure 1 shows the system window for entering the patient data. The input data for a patient are: a) The patient information data such as the patient ID number, patient's name, address, etc.

b) The patient's blood gas information (i.e. PCO2 and SPO2)

c) The lung mechanics data (i.e. airway resistance, RES, and lung compliance, COMP)

d) The breathing parameters that are the set tidal volume, VTS, total respiratory rate, F2, positive end-expiratory pressure, PEEP, the inspiratory to expiratory time ratio, TI and TE, the inspired fraction of oxygen, FIO, and the ventilatory mode, VM. VM is zero if the ventilator is in volume control/assist mode, and it is equal to 1 if the ventilator is in the pressure control/assist mode.

e) Maximum limits for tidal volume, VMAX, and pressure, PMAX.

f) Ventilatory parameters that are measured tidal volume, VTMS, spontaneous breathing rate, FSP, and the measured inspiratory pressure, SPN.

g) Other patient's data (such as ideal body weight and body temperature)

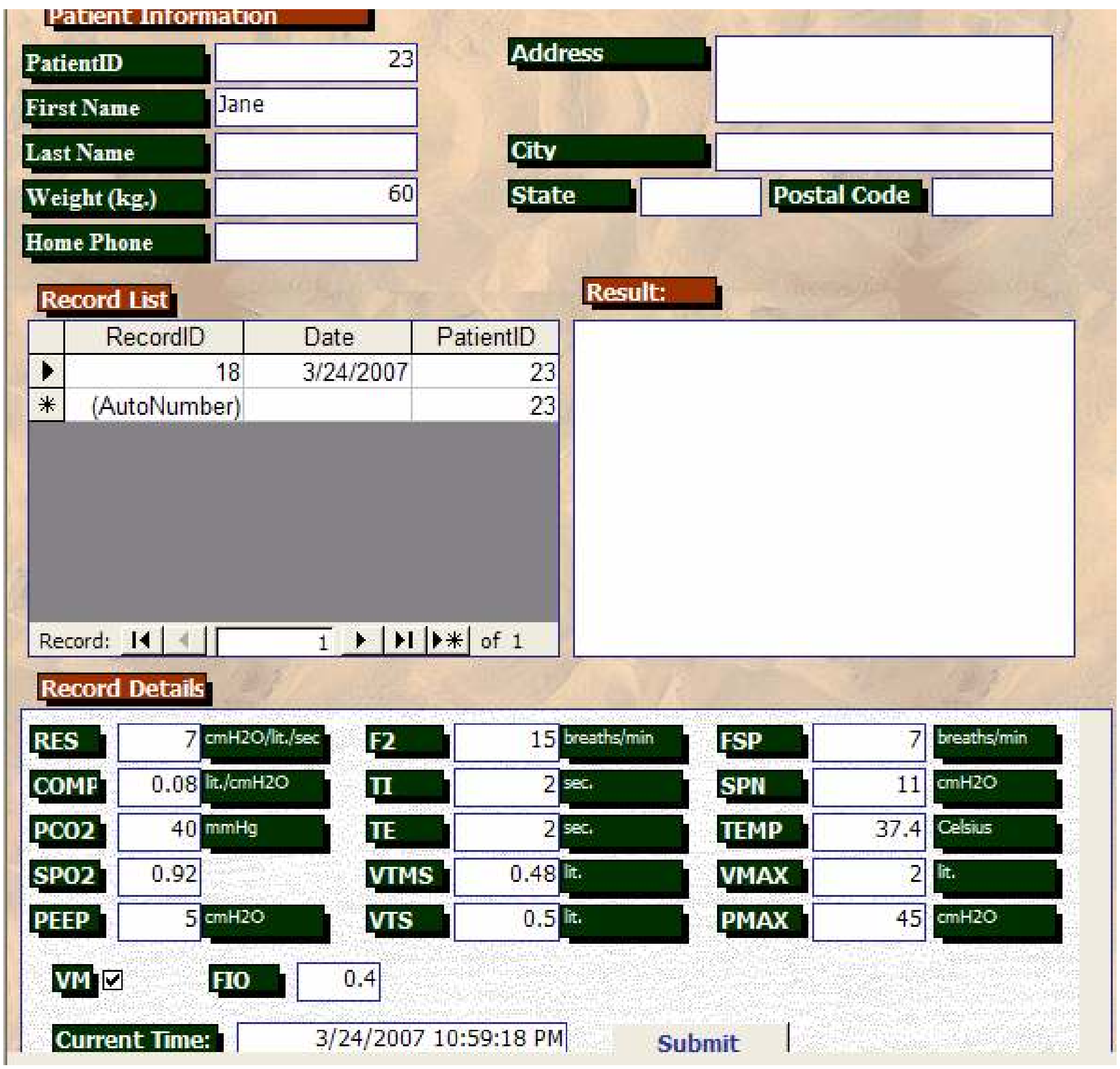

Figure 1- A patient's record window

After the data is submitted, the system's algorithm computes the optimal level of ventilation. This is done either based on the patient's ideal body weight, PCO2, and SPO2 data, or if PCO2 is not provided, the required ventilation is computed based on the patient's ideal body weight and his/her body temperature. The optimal breathing rate is computed based on the mechanical properties of the lungs to minimize the breathing work rate. This is done by using a modified version of an equation by Otis et al. [10]. The respiratory dead space is calculated and the respiratory rate and tidal volume are compared with the safe limits computed by the algorithm and are adjusted if necessary. The peak inspiratory pressure is calculated (in the pressure control/support mode) by dividing tidal volume by the respiratory compliance and adding the result by PEEP. The inspiratory to expiratory time ratio is adjusted if necessary to prevent the build up of intrinsic peep. This adjustment is done if the expiratory time is too short compared to the respiratory time constant which is the product of respiratory compliance and airway resistance. The respiratory period is also limited and cannot be shorter than 5 times the respiratory time constant.

The levels of FIO and PEEP are calculated to prevent hypoxemia, hyperoxemia, and oxygen toxicity. The PEEP level is calculated in relation to FIO to avoid reduced cardiac function and barotrauma. The patient condition is checked to see if respiratory muscles show some strength in handling spontaneous breathing. If the spontaneous effort is weak, weaning is not recommended. Otherwise, if the patient's effort is found to be acceptable, the system checks other patient's variables such as PCO2, SPO2, FIO, and PEEP, and if they are found within predefined acceptable ranges, initiation or continuation of weaning is recommended. The system produces new optimal ventilatory parameters as well as suggestions regarding weaning. It also checks for a number of other safety measures and comes back with recommendations and warning messages if appropriate to the clinician. An example of the system's output for a patient is shown below.

WEANING IS SUGGESTED, CONSIDER REDUCING CONTROLLED VENT.
Total Required Minute VENTILATION = 6.6852
TOTAL FREQUENCY 12.3988
PEEP = 5
FIO2 = 0.4
VTS = 0.5392
TOTAL INSPIRATORY PRESSURE = 11.7398
TE = 3.2261
TI=1.6131
PLEASE COME BACK.

An example output of the system for a patient

Discussion and Conclusion

A new decision support system has been introduced in this paper. In addition to providing treatment advice, the system can also be used for automatic control of weaning. Closed-loop mechanical ventilation has already been used successfully worldwide. Adaptive Support Ventilation (ASV) by Hamilton Medical is a well-known mode of a patented closed-loop system which is marketed under license of US Patent# 4,986,268 [7]. Also, Smart Care by Drager Inc. is another commercially available closed-loop technique for mechanical ventilation. Despite these however, most of the existing mechanical ventilators are still mainly open-loop controlled devices. These machines have many parameters that need to be properly set by the clinicians and an effective decision support system can be used as a valuable tool in making the right decision for the patient.

An effective decision support system should preferably be flexible and versatile so that it can be used in different ventilatory control/assist modes for a wide range of patients. The FLEX decision support system was designed with these important considerations in mind. Although model-based expert systems can be informative to the physician, but a decision support system cannot be conveniently used at bed-side if it requires large amount of patient data. A further objective of the design of this system was to make it user friendly and to minimize the input data to what was essential. FLEX incorporates the features of the ASV closed-loop system which was originally introduced in 1991 [7], and it further includes many other features for control of oxygenation and weaning. The system is designed both as an advisory tool and as a closed-loop system for weaning and a US patent application has been filed on the system.

If used as an advisory open-loop system, the ventilator as well as patient input data can be manually provided. The system can be used in this mode as often as necessary while the patient data is memorized and plotted versus time by the system. The recommendations of the advisory system have been found to be in line with clinical determinations in numerous retrospective comparisons.

The closed-loop version of the system however, is designed with a module which automatically receives ventilator and patient data. This module is designed to receive its inputs from a ventilator as well as an oximeter and an end-tidal CO_2 analyzer. The closed-loop version is implemented using a microprocessor whose outputs are converted to analog and applied directly to the ventilator. This system has had an initial testing by using a Siemens Servo Ventilator 300A.

In conclusion, although the open-loop system has been successfully tested versus many clinical data, and the closed-loop weaning systems has had a successful initial testing, but both systems need further detailed clinical evaluations and assessments. It is hoped that FLEX will have the potential necessary to become an effective aide in the treatment and management of mechanically ventilated patients.

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