VentPlan: a Ventilator-Management Advisor

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Abstract

VentPlan assists physicians, nurses, and respiratory therapists in the management of artificial respiration for critically ill patients in the intensive-care unit (ICU). VentPlan interprets clinical observations, monitored data, and arterial-blood-gas analyses to make recommendations for setting the ventilator. The VentPlan interface allows users to examine the physiologic model, to inspect details of the data on which the model is based, and to exercise the model to try out different ventilator settings before they implement a new setting. We also report here a preliminary evaluation of VentPlan's ability to predict the arterial oxygen and carbon-dioxide tensions following adjustments to the ventilator. We conclude that VentPlan's physiologic models are acceptably accurate for predicting the effects of small adjustments of the ventilator.

Introduction

We have previously described VentPlan, an application to assist users (physicians, nurses, and respiratory therapists) in the management of artificial respiration for patients in the intensive-care unit (ICU) [2, 3]. A belief network helps to refine a patient-specific quantitative physiological model that is used to predict the effects of changes in the ventilator settings [3, 4]. A multiattribute value model ranks proposed settings for four controls of the ventilator (fraction of inspired oxygen (FIO2), rate of ventilation (RR), tidal volume (V_t), and positive end-expiratory pressure(PEEP)) [1]. VentPlan recommends the settings with the highest ranking, and provides a text warning if the difference between the rankings of the current and recommended settings exceeds a predefined threshold.

The VentPlan Interface

We have implemented an interface that helps users to understand VentPlan's interpretation of the patient's physiology. The VentPlan interface is a monitor panel that displays pulse-oximeter data, arterial-blood-gas (abg) analyses and measurements of the cardiac output, along with the current and recommended ventilator settings and a text message interpreting the difference between these values. A graphical display presents the time-ordered patient data that form the basis for the estimated values of the physiologic-model–parameters, and allows the user to superimpose the model predictions on graphs of the data. The user may inspect the model parameters and predictions for the model variables in a separate panel. The interface allows users to modify the data display, to begin a simulation, or to enter a new diagnosis. A description of the development of this interface appears elsewhere in these proceedings [5].

The user asserts or retracts diagnoses by clicking on buttons corresponding to the diagnoses recognized by the belief network. Adding a new diagnosis or retracting a previous diagnosis causes a reevaluation of the belief network and a reinterpretation of the patient observations. The user can explore the effects of any proposed ventilator setting by adjusting the controls of the patient simulator.

Demonstration

We shall show VentPlan running on a Macintosh II computer, using patient data captured from the Emtek data system at the surgical ICU at the Palo Alto Veterans Administration Medical Center (PAVAMC). For the demonstration, the data are read from a file to simulate data arriving to a real-time monitoring application. We shall show that VentPlan is able to maintain a data-analysis cycle of under 1 minute. Interaction with the patient simulator will demonstrate how the user can explore the effects of proposed ventilator settings.

VentPlan requires a Macintosh II computer with a numeric coprocessor, and a monitor with a minimum size of 768 x 1024 pixels.

Evaluation

We evaluated the design of the interface for VentPlan by showing our intended users prototypes of the interface. Our users have recognized the relationship of the interface controls to the physical ventilator, and they prefer the interface based on the physical device to other designs based on a spreadsheet layout [5].

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To evaluate the ability of VentPlan's physiologic model to predict the effects of changes to the ventilator settings, we compared the predictions made by VentPlan at the time of ventilator adjustments with measurements of the patients' subsequent responses.

We examined retrospectively the online records from the Emtek data system for 10 patients randomly selected from those admitted to the PAVAMC surgical ICU over a 2-month period. We analyzed data from the records covering the period from time of admission until the ventilator rate had been reduced to below four breaths per minute (nine patients), or the patient had died (one patient). The procedures these patients underwent were coronary-artery bypass grafting (CABG) (5), cardiac valve replacement (2), sternal rewiring (1), exploratory laparotomy (1), and subdural hematoma evacuation (1). One of the patients recovering from CABG was transferred to the surgical ICU after suffering a cardiac arrest on the ward. There were 55 ventilator adjustments during 355 hours of monitoring of these 10 patients. The ventilator changes were made to the FIO2 in 40 cases, and to either the RR or the V_t in 20 cases. The average change in FIO2 was 0.10, and the average change in the product of rate and V_t was 2.4 liters/minute. Because this study looked at the online data record retrospectively, the VentPlan system had no influence on the frequency or magnitude of changes to the ventilator controls.

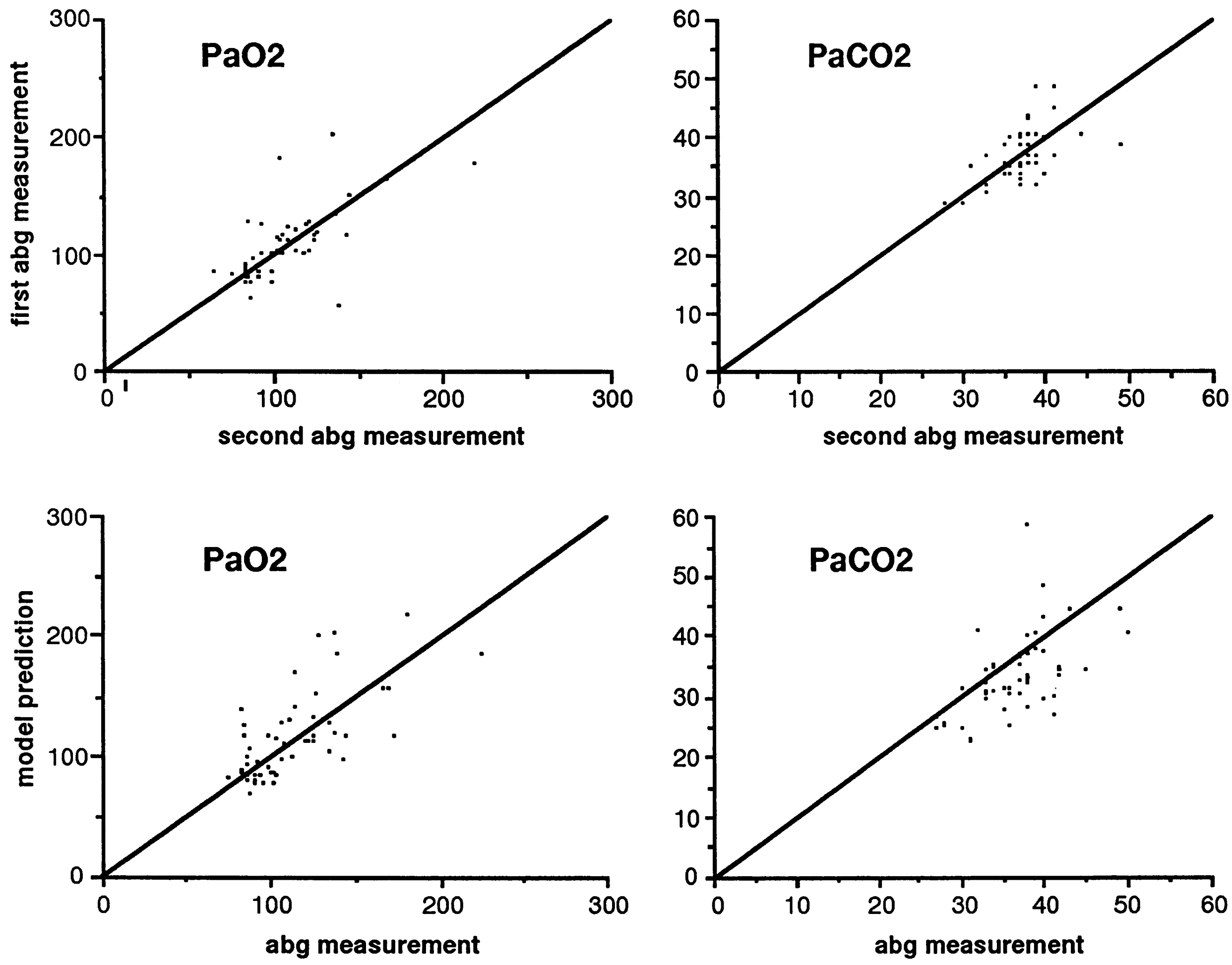

Figure 1. Prediction accuracy for abg values in the absence of a change in the ventilator settings (top) and after changes in the ventilator settings (bottom). When there has been no change in the ventilator setting, the first abg predicts the second (top). After a ventilator change, the physiologic model—calibrated by an initial abg—predicts the subsequent abg measurement (bottom). The line of identity is plotted for reference. PaO_2, $PaCO_2$: partial pressures of arterial oxygen and carbon dioxide, respectively, in millimeters of mercury.

Table 1. Prediction errors and variances of repeated abg analyses with and without changes in the ventilator settings.

	no ventilator-setting changes		with ventilator-setting changes			
	average absolute difference	variance σ^2_{nvc}	average absolute prediction error	variance σ^2_{nvc}	standard error	coefficient of error
PaO2:	14.1	526	19.9	740	**14.3**	**0.11**
PaCO2:	2.7	13.4	4.6	32.0	**4.3**	**0.12**

Absolute difference: abg prediction minus abg measurement (In the absence of an intervening ventilator-setting change, the first abg measurement predicts the second); coefficient of error: standard error/mean prediction; σ^2_{nvc}: prediction variance after ventilator changes; σ^2_{vc}: interobservation variance with no ventilator changes; standard error: $\sqrt{\sigma^2_{vc} - \sigma^2_{nvc}}$; PaO2, PaCO2: partial pressures of arterial oxygen and carbon dioxide, in millimeters of mercury.

We first examined the variability of abg measurements that could not be attributed to changes in the ventilator settings. There were 50 occurrences of repeat abg analysis with no intervening changes in the ventilator settings. We considered an abg measurement to be a repeat measurement if it was obtained within 4 hours of the first measurement. We calculated the interobservation variance (σ^2_{nvc}) when no ventilator changes occurred between measurements (Table 1). These data are plotted in the top half of Figure 1.

We next compared the model's predictions for PaO2 and PaCO2 with the subsequent measurements for PaO2 and PaCO2 after each change in the ventilator settings. We subtracted the interobservation variance (σ^2_{nvc}) from the variance we observed in the absence of ventilator changes (σ^2_{vc}) to calculate the variance in predictions that could be attributed to inaccuracy in the physiologic model. The standard error for predictions of the PaO2 was 14.3 mmHg; that for predictions of the PaCO2 was 4.3 mmHg. These data are listed in Table 1; they are plotted in the bottom half of Figure 1.

The mathematical models represent a simplification of the details of cardiopulmonary physiology, and we do not expect them to provide accurate predictions in all situations. For many changes in the ventilator controls that are actually encountered during ICU monitoring, however, our current models appear to be acceptable.

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