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Decision support of inspired oxygen selection based on Bayesian learning of pulmonary gas exchange parameters

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Summary

Objective: To investigate if the real-time Bayesian learning of physiological model parameters can be used to support and improve the selection of inspired oxygen fraction.

Methods and material: Supporting the selection of inspired oxygen fraction relies on predictions of arterial oxygen saturation. The efficacy of using these predictions to select inspired oxygen was tested retrospectively in a system for estimating gas exchange parameters of the lung (Automatic Lung Parameter Estimator, ALPE). For the predictions to offer effective decision support they need to be accurate and above all safe. These qualities were tested with data from 16 post-operative cardiac patients, using two different tests. The aim of the first test was to assess retrospectively if the predictions could have supported clinical decisions. The second test sought to establish if the predictions could support improving the efficiency of inspired oxygen selection during an ALPE oxygen titration.

Results: The predictions were found to be reasonably accurate, and most importantly safe in both of the tests.

Conclusion: The method described can be used to support the selection of inspired oxygen fraction, and it has the potential to improve the efficiency of inspired oxygen selection during an oxygen titration.

1. Introduction

Oxygen delivery to the tissues can be reduced by insufficient blood supply to the tissues, or low oxygen concentration in the blood. Low oxygen

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concentration in the blood is often caused by abnormalities in the exchange of gas between alveoli and lung capillaries. These abnormalities present in various patient groups including: patients residing in the ICU on mechanical ventilation; patients with pulmonary congestion due to left sided heart failure; and in patients following routine major surgery [1—5]. Therefore, measurement of the gas exchange properties of the lungs could be an important part of the monitoring and prevention of hypoxia.

Recently a system has been developed for measurement of the lungs' gas exchange properties from non-invasive clinical data (the Automatic Lung Parameter Estimator, ALPE) [6]. ALPE automatically captures, records, and displays data from a ventilator, gas analyser and a pulse oximeter. ALPE then processes these data to produce a description of pulmonary gas exchange using a two parameter model of oxygen transport [6—8]. These two parameters represent: the percentage of blood flowing through non-ventilated regions of the lung (shunt); and the ventilation-perfusion mismatch (fA2). fA2 is the fraction of the alveolar ventilation in a lung compartment containing 90% of the non-shunted blood flow. A fA2 value of 0.9 therefore indicates a ventilation perfusion ratio of 1, with 90% of the ventilation going to 90% of the perfusion. The model's description of pulmonary gas exchange has been shown to describe patient data in a large number of studies, including a study describing more that 100 patients [2,6, 9—11].

Identification of the two parameters describing gas exchange requires measurement, at steady state, of a patient's ventilation. These measurements include arterial oxygen saturation (S_pO_2) measured at different levels of inspired oxygen fraction (F_iO_2). F_iO_2 is varied in a number of steps to achieve a required range of S_pO_2 values (85—100%). After each step change in F_iO_2 several minutes are required until steady state is achieved. This means that a procedure including five step changes in F_iO_2 usually takes ten to fifteen minutes to perform [6]. Selection of the most appropriate set of F_iO_2 values is therefore important to minimize the duration of the procedure, and hence improve the clinical acceptance of ALPE.

Currently the clinician selects the F_iO_2 values using their intuition and experience of using ALPE to achieve a range of S_pO_2 values sufficient to estimate pulmonary gas exchange parameters. This selection is difficult when reducing F_iO_2, where a poor choice of F_iO_2 may reduce S_pO_2 more than expected. The result is that when decreasing F_iO_2 caution is taken to ensure that S_pO_2 remains above 85%. This may result in a sub-optimal number of F_iO_2 steps being taken.

There is therefore a need for a system which helps guide the clinician to the next most appropriate F_iO_2. A system which quickly predicts a patient's S_pO_2 level at any F_iO_2 could guide the clinician in selecting the most appropriate F_iO_2. Such a system could reduce the number of F_iO_2 steps taken, and hence reduce the time required to perform an ALPE procedure.

Bayesian learning has been shown to be effective in many areas including the setting of drug doses in clinical trails [12,13], and in the estimation of compartmental model parameters [14,15]. These concepts can be applied to the estimation of ALPE gas exchange parameters in order to select a dose of oxygen, F_iO_2, during an oxygen titration. This paper describes how Bayesian learning is used in ALPE for the real-time prediction of S_pO_2 at any chosen F_iO_2. This Bayesian version of the ALPE system (ALPE Bayes) is tested retrospectively using clinical data to investigate the accuracy and safety of the S_pO_2 predictions, and hence test if the system is able to give guidance to the clinician on selecting the next most appropriate F_iO_2 level.

2. Materials and methods

2.1. Bayesian learning in ALPE

This section describes the application of Bayesian learning in the ALPE system. That is: the specification of a priori distributions describing gas exchange parameters in different patient groups; the update of the joint parameter distributions on data collection, using Bayes theorem; and the use of the joint parameter distribution to predict the probability distribution of S_pO_2 at any F_iO_2.

2.2. A priori distributions

A number of patient groups exist for which measurement of the gas exchange properties of the lung may be important. Different groups can have very different lung function, for example, patients with adult respiratory distress syndrome will typically present differently from those following routine major surgery. Knowledge of inter-group variation is currently represented in ALPE as a priori distributions for gas exchange parameters (shunt and fA2) for five previously studied patient groups (Table 1). These groups are long term intensive care patients, post operative patients, patients with heart failure, pre-operative patients, and normal subjects. Table 1 shows the mean and standard deviation for both parameters for each patient group. The shunt values used for the intensive, post-operative, heart failure