Title: Measuring Venous Oxygen Saturation Using the Photoplethysmographic Waveform.

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Introduction

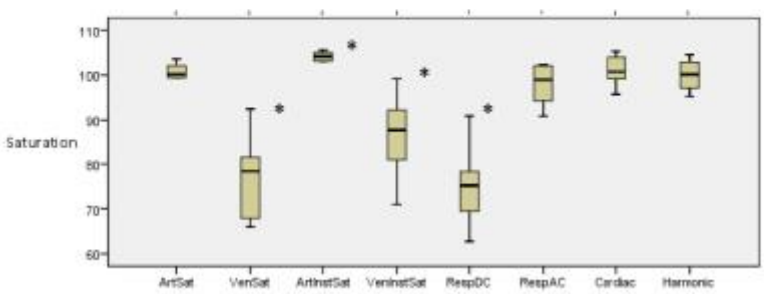
The pulse oximeter is now a standard-of-care monitor. In its most basic form it measures the arterial oxygenation saturation. It accomplishes this through the use of the photoplethysmograph waveform (PPG) at two or more wavelengths. Advances in digital signal processing are allowing for a re-examination of these waveforms. It has been recognized for some time that the movement of venous blood can be detected (1, 2) using the PPG. For the most part, this phenomenon has been seen as a source of artifact which interferes with calculation of arterial saturation. On the other hand, if venous saturation can be reliably measured, interesting new possibilities are opened. We hypothesize that the PPG waveform, obtained non-invasively by modern pulse oximeters, can be analyzed via digital signal processing to infer the venous oxygen saturation.

Methods

Fundamental to the successful isolation of the venous saturation is the identification of PPG characteristics that are unique to the peripheral venous system. Two such characteristics have been identified. First, the peripheral venous waveform tends to reflect atrial contraction (e.g. a-c-v waveform). This leads to a tri-lobed configuration with the result that diastolic beats are detectable in the PPG(1, 2). Second, ventilation tends to move venous blood preferentially due to the low pressure and high compliance of the venous system(3). Red (660nm) and IR (940nm) PPG waveforms were collected from both the finger and esophagus from 10 cardiac patients undergoing CABG during the peri-operative period (intra-op and post-op). These waveforms were analyzed using algorithms written in Mathematica (Wolfram Research). ArtSat = conventional time domain method of calculating arterial saturation. VenSat = time domain method using DC (Hz <0.45) ArtInstSat = instantaneous saturation determination (upper limit). VenInstSat = instantaneous saturation determination (lower limit). RespDC = frequency domain using DC @ resp frequency. RespAC = frequency domain using DC @ cardiac frequency. Cardiac = frequency domain using cardiac frequency. Harmonic = frequency domain using higher harmonics of cardiac frequency.

Results

The eight saturation algorithms (ArtSat, VenSat, ArtInstSat, VenInstSat, RespDC, RespAC, Cardiac, and Harmonic) were applied to the esophageal PPG data set.The results are shown in the figure using box-and-whisker plots. The asterisk indicates significance difference from ArtSat using Wilcoxon signed-rank with Bonferroni correction (p<0.0071).



Discussion

This is a preliminary report designed primarily to introduce new methods of PPG analysis. The early results are encouraging with three methods of analysis (VenSat, VenInstSat & RespDC) detecting lower saturation blood. The next step is to confirm the accuracy of the measurement by comparing them to a gold standard (i.e. venous blood gas).

1. Shelley KH et al, J Clin Monit. 1993 9(4):283-7.
2. Shelley KH et al, Anesth Analg. 2005 100(3):743-7.
3. Wardhan R, and Shelley K., Curr Opin Anaesthesiol. 2009 22(6):814-21.

Funding: Departmental Funding

Summary: This abstract examines several different methods of calculating SvO2 from conventional PPG waveforms. Three methods successfully detected lower saturation blood.