Photoplethysmogram Baseline Modulation as a Measure of Respiratory Effort: A Free Breathing Protocol with Progressive Flow Restrictions at the Mouth

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Introduction: The manifestation of respiratory components in the photoplethysmogram (pleth) has been well documented in the literature [1,2] with much of the activity in this area focusing on the derivation of respiratory rate (RR). RR may be determined from an analysis of the periodicity of respiratory modulations present in the signal [3,4]. However, the strength of these modulations may be indicative of thoracic pressure changes associated with the effort to breathe that are transmitted to the peripheries through the vasculature [5,6]. Here we report on a preliminary study to determine the effect of changing airway pressures at the mouth on modulations in the pleth baseline for two finger sensors and an ear sensor.

Method: With institutional review board approval and written informed consent, a convenience sample of 4 healthy adult volunteers was studied. These had been pre-screened and completed physical exams. During the trials, the subjects were positioned comfortably in a chair with the pulse oximeter sensors attached. A facemask was attached to each subject consisting of a spirometer containing a number of interchangeable flow resistors (5, 20 and 50 cmH2O/l/s linear resistors (Hans Rudolf Inc., Kansas City, MO)). Airway pressure signals at the mouth and pleth waveforms were synchronized and recorded via a custom data acquisition system. All subjects undertook both a constriction-on-inhalation protocol and a corresponding constriction-on-exhalation protocol. The value of flow constrictor resistance was set in turn to 0, 5, 20, 50 and 0 cmH2O/l/s for five consecutive periods of approximately 480 seconds. The subjects were allowed to breathe freely, i.e. respond freely to the changing airway resistance.

Results: We generated time series of the pleth baseline modulations associated with respiratory activity. An example is shown in figure 1(a). The modulations were extracted using a bandpass filter with a range of 0.05 to 0.50Hz. The running median absolute deviations of the modulations were computed and are also shown in the figure as separate signals above the modulations. Note that these are factored by 10 to display them above the modulation signals. In addition, we plotted these baseline modulation strengths against the measured total flow resistance back-calculated from the pressure and flow signals. This is shown in figure 1(b). One signal from one probe experienced a large gain change during the run which rendered the data unusable. This was excluded from the analysis. A total of 23 signals (= 4 patients, inhalation and exhalation, 3 probes each minus the excluded signal) were used in the analysis. We found a generally increasing trend between the pleth-based respiratory effort parameter and increasing flow resistance for all three probes. Considering only the difference between the baseline (no resistor) to the highest value of constriction (50 cmH2O/l/s), it was found that all respiratory efforts increased. It was noted that the respiratory effort behavior was associated with an increase in baseline modulation at the frequency of
respiration of the arterial blood pressure trace and, in general, the subjects also reduced their respiratory rates with increasing resistance.

Conclusions:
The results suggest that the pleth may provide a measure of changing upper airway dynamics indicative of the effort to breathe. In practice this may be useful for identifying upper airway obstructive events and/or lung compliance changes. A larger cohort would be required before more definitive conclusions could be reached. The development of a simple pleth-based non-invasive continuous measurement of the effort to breathe could enable such a respiratory effort parameter to be available across multiple areas of care. Alone, or in conjunction with other parameters such as SpO2 and Respiration Rate (also available from the pleth), it may provide early warning of impending respiratory compromise including obstructive apneic events.

Figure 1: (a) Pleth-Based Respiratory Effort over time. (b) Aggregated Effort v Resistance Plot for Subject RE001 (Free Breathing/Exhalation Protocol)
Three probes were used. Left Ear Sensor - Nellcor D-YSE (blue trace). Left Index Finger - Nellcor Max- A (red trace). Left Ring Finger - Nellcor Max- N (black trace). In (a) the running median absolute deviations of the modulations are factored by 10 to aid their visualization above the raw modulation signals. In (b) the colors correspond to groupings from resistance calculated for each resistor used.

References:
4. Addison PS, Watson JN, Mestek ML, Ochs J.P., Uribe A.A., Bergese S.D. ‘Pulse Oximetry-Derived Respiratory Rate in General Care Floor Patients’. J Clin Mon Comp. 2014; May, Published Online.
