Comparison of a Non-Invasive Volume Monitor to End-Tidal CO2 Measurements in Changing Time in Minute Ventilation

Monitor respiratory performances in non-intubated patients remains a major challenge and is often inadequate, despite new clinical guidelines and requirements. Conventional monitoring technologies are often incapable of identifying early signs of respiratory compromise and of indirect (secondary) indicators like oxygen saturation (SpO2) and capnography (EtCO2). The introduction of breath-to-breath monitoring has led to new challenges for monitoring technologies. Recently, capnography has become more widely used, unfortunately, end-tidal CO2 (EtCO2) measurements in non-intubated patients remains limited due to the large time disparities in signal processing. These time disparities all contribute to the measurement errors observed in non-invasive capnography. A non-invasive respiratory volume monitor (RVM) that is capable of continuous measurement of minute ventilation (MV), tidal volume (TV) and respiratory rate (RR) has recently become available for clinical use. The RVM has been previously proven to provide accurate TV and RR measurement errors (< 10% for MV and TV and <1% for RR). Here we evaluate the ability of both standard capnography and the RVM to monitor respiratory performance in non-intubated volunteers in a controlled environment without supplemental oxygen.

Methods

Equipment and Pilot Study: Continuous RVI (ExSpiron, Respiratory Monitoring, Waltham, MA) and capnography data (Capnomatic 20, SmartCapnography Plus & Fibertrac Set, CardioVu, Manfild, WI) were collected from 39 subjects (14 females, age 48.5 ± 3.3 yrs, BMI: 27.9 ± 6.4 kg/m2). RVI data was interpolated from thoracic bioimpedance data collected via an electrode pad placed on the chest, as shown in Figure 1.

Experimental Design: Each subject performed four 2.5 min trials of normal breathing and four 2.5 min trials of "slow" and "fast" breathing at a 2-ppm defined RR (5 and 25 breaths/min, respectively). The order of the breathing trials for each patient, capnography data were collected with a scope cannula (CardioVu SmartCapnography Plus Oral/ Nasal) and in the other A 2-ppm defined RR with an in-line sensor (Exspiron, CardioVu Fibertrac Set) was used. We ensured that each patient performed 5 normal, 1 slow and 1 fast 2.5 min trials with each of the 2 monitoring techniques and we balanced the order of trials such that half of the subjects used the in-line sensor and half used the sampling cannula.

Results

Figure 2: Comparison of the performance of an RVM and a capnograph during a substantial change in ventilation. Top: TV-recorder respiratory trace over the course of two 2.5 min-long cycles. At time t=0 the subject was asked to hyperventilate at a respiratory rate of 25 liters (by mouth) and maintain that rate for the duration of one 2.5 min-long cycle. After the end of the 2.5 min-long cycle the subject was asked to transition his breathing to hyperventilation pattern at 1 L/min/hour for a second 2.5 min-long cycle, with shallow breathing. Middle: The TV reported by the RVM (Blue, left y-axis) along with the TV, reported by the capnograph (Black, right y-axis). The TV reported by the RVM and the capnograph match well with each other until the transition at time t=2.5 min. At this point, the RVM-based RR settles to the new rate in 32 seconds, while the capnograph-based RR takes 71 seconds. In this patient during normal baseline breathing was between 15 and 36 rpm. Bottom: The TV recorded by the RVM (Black) and the capnography-based breathing pattern matches the respiratory rate during periods of constant rate. However, after the transition from 25 to 2.5 min/ breaths, the RVM-based RR settles to the new rate in 32 seconds, while the capnograph based RR takes 71 seconds.

A strong negative correlation between changes in MV and changes in EtCO2 was observed. This correlation was similar for nasal cannula sampling and in-line sampling (0.60 ± 0.1 vs 0.70 ± 0.1 mmHg/L/min, p<0.05). Figure 3A. Over the course of the study, subjects modulated their MV by nearly ten-fold, from 26.0 ± 1.4 L/min (mean ± 1 SEM) while hyperventilating, to 2.1 ± 0.5 L/min while hypoventilating hyperventilating with the in-line sensor, and 23.6 ± 0.6 L/min to 2.9 ± 0.2 L/min with the sampling cannula (Figure 3B). Meanwhile, the corresponding EtCO2 measurements ranged from 22.5 ± 1.1 mmHg (hyperventilation) to 38.6 ± 0.6 mmHg (hyperventilation) with the in-line sensor and 25.9 ± 0.4 mmHg to 40.3 ± 0.6 mmHg with the sampling cannula (Figure 3C). No EtCO2 values above 44 mmHg were recorded.

Conclusions

In-line sampling capnography measurements were found to be considerably more complex than nasal capnometry measurements (mean difference 4.1 mmHg, 95% confidence interval 2.1-6.2 mmHg). Bland-Altman analysis of the two capnography techniques (Figure 4) revealed a systematic bias toward lower readings in nasal capnometry, likely the result of side air being pulled in with the exhaled air, reducing CO2 concentration relative to that measured with a sealed inline sensor setup. In the case of RVM measurements, a clinically useful approximation of arterial CO2, the large blood volume in a resting individual acts as a buffer, slowing down the rate of change of arterial CO2, making EtCO2, at best a lagging indicator of ventilation status. RVM is a potentially a better tool to measure adequacy of ventilation in non-intubated patients since it provides a direct measure of MV.

In a controlled environment, using an in-line sensor capable of capturing 100% of exhaled air, EtCO2 measurement was unable to rapidly report rapid changes in ventilation. In healthy subjects, we found good correlation between decreased MV and decreased EtCO2 measurements, but during transition periods, RVM provided more timely reporting of ventilatory changes. The commonly used nasal sampling method introduced a systematic bias that could further delay clinical relevance of respiratory efforts. In some settings EtCO2 may be a clinically useful approximation of arterial CO2, the large blood volume in a resting individual acts as a buffer, slowing down the rate of change of arterial CO2, making EtCO2, at best a lagging indicator of ventilation status. RVM is a potentially a better tool to measure adequacy of ventilation in non-intubated patients since it provides a direct measure of MV.

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