Non-Invasive Respiratory Volume Monitoring v. Capnography at Various Respiratory Rates in Non-Intubated Subjects

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**Introduction:** Real-time respiratory monitoring in non-intubated patients has been integrated into clinical guidelines; yet standard monitoring technologies are often inadequate to identify early signs of respiratory compromise. Recently capnography has become more widely used, but end-tidal CO₂ (EtCO₂) measurements can be inaccurate, with variations in sensor positioning, changes in breathing pattern and dilution from flow of supplemental oxygen. Here we compare capnography to a non-invasive respiratory volume monitor (RVM) that provides continuous, accurate measurements of minute ventilation (MV), tidal volume (TV) and respiratory rate (RR) in subjects in a controlled environment without supplemental oxygen.

**Methods:** 25 subjects (5 females, age: 47.5 ±10.8 yrs; BMI: 28.9 ±8.6 kg/m²) were studied. Impedance based RVM (ExSpiron, Respiratory Motion, Inc., Waltham, MA) and capnograph (Capnostream 20, Covidien, Mansfield, MA) data were collected continuously. Each subject performed 4 2.5 min trials while breathing normally and 4 2.5 min breathing trials 3 defined RRs (5, 25, 30 breaths/min). Capnography data were collected with a scoop cannula (Covidien Smart CapnoLine Plus Oral/Nasal) in all patients. In 15 subjects data was also collected in similar tests using a snorkel mouthpiece with an in-line EtCO₂ sensor (Covidien Filterline Set). Pearson correlations were used to compare the from the RVM & capnograph during periods of steady breathing & paired t-tests used to compare the rate of change of RR, MV & EtCO₂ measurements between the 2 devices as breathing patterns changed.

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**Results:** Given the minimal difference in EtCO2 and RR measurements capnography data from the sampling cannula and in-line sensor were pooled for analysis. During steady breathing, the correlation between RVM & capnography RR was $0.98 \pm 0.05$ (mean±SD) & the average difference in RR was $0.7 \pm 0.4$ breaths/min. During transitions between breathing patterns, the RVM-based RR reflected the change over $32.1 \pm 1.2$s, while the capnography-based RR was slower to respond ($63.3 \pm 4.8$s, significantly greater than the RVM, $p<0.001$; Figure 1A), The differences in the rate of change of MV & EtCO2 were even more pronounced: the RVM MV reflected the change in respiratory pattern in $31 \pm 1.4$s on average. EtCO2 changes were notably slower, often failing to reach a new asymptote over 150 seconds. During the study subjects modulated their MV from $25.6 \pm 2.9$ L/min (mean ±SEM) while hyperventilating to $2.7 \pm 0.3$ L/min during hypoventilation. The corresponding EtCO2 measurements ranged from $23.8 \pm 1.1$ mmHg (hyperventilation) and $37.9 \pm 0.9$ mmHg (hypoventilation). No EtCO2 values above 44 mmHg were recorded.

**Conclusions:** in this study environment, more well controlled than a clinical setting, with cooperating subjects, EtCO2 measurements lacked the fidelity to adequately capture rapid changes in ventilation regardless of whether the EtCO2 sampling was done with an in-line sensor, simulating a properly-seated face mask capturing all of the expired air, or with an oral/nasal cannula. While 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 alveolar CO2, essentially rendering EtCO2 measurements a lagging indicator of changes in ventilation. In a steady state, the RVM correlated very well with the EtCO2 measurements, but during transient periods provided timelier reporting of ventilatory changes. RVM is potentially a better tool to measure adequacy of ventilation in non-intubated patients.
Figure 1: Comparison of the performance of an RVM and a capnograph during a substantial change in ventilation.

**Top:** RVM-recorded 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 b/min (by metronome) and maintain that rate for the duration of one 2.5 min-long cycle. At the end of the cycle the subject was asked to transition his breathing to a hypoventilation pattern at 5 b/min for a second 2.5 min-long cycle, with shallow breaths.

**Middle:** The MV reported by the RVM (blue, left y-axis) along with the EtCO\(_2\) reported by the capnograph (black, right y-axis). The MV reflects the change in respiratory pattern instantaneously, reaching a new asymptote of approximately 3 L/min within 25 seconds of the transition. Meanwhile the EtCO\(_2\) continues to climb from 24 mmHg to 34 mmHg over the second 2.5 min-long cycle. The EtCO\(_2\) recorded in this patient during normal baseline breathing was between 35 and 36 mmHg.

**Bottom:** The RR reported by the RVM (blue) and the capnograph (black) accurately match the metronome-set RR during periods of constant rate. However, after the transition from 25 to 5 b/min, the RVM-based RR settles to the new rate in 32 seconds, while the capnograph-based RR takes 71 seconds.