Opioids are commonly used for pain control in patients undergoing orthopedic surgery. However, they often cause complications known as opioid-induced respiratory depression (OIRD) and post-operative apnea (POA). To reduce the risk of these complications, continuous respiratory monitoring is necessary both for intubated and non-intubated patients. Until recently, reliable and continuous methods for respiratory monitoring have only been available for intubated patients. Capnography, one such method, is an adequate solution for confirming endotracheal (ET) tube placement and monitoring adequacy of ventilation in intubated patients; however, it has proven unreliable in non-intubated patients.1,2 Variables such as sensor positioning, changes in the patient's position, and patient movement can all distort the measurements provided by capnography in non-intubated patients. Because it is an indirect indicator of respiratory compromise, capnography is often delayed and even false. A novel, noninvasive respiratory volume monitor (RVM) can provide real-time accurate measurements of minute ventilation (MV), tidal volume (VT), and respiratory rate (RR) in both intubated and non-intubated patients. Studies have indicated that the RVM measurements are accurate (errors less than 10% for MV and ±3% for RR). For here, we studied the relationship between EtCO₂ and MV in three separate intubated surgical patients under general anesthesia (GA), non-intubated surgical patients under spinal anesthesia (SA) and awake, spontaneously breathing volunteers.

Methods

Continuous RVM data (ExSpiron, Respiratory Motion, Inc., Waltham, MA) were collected from 153 patients in 3 groups. Group 1: 54 patients (age: 41.2 ± 12.1 years; BMI: 21.2 ± 3.0 kg/m²) under general anesthesia (GA), intubated patients and monitored by the sampling nasal cannula. Group 2: 52 patients (age: 50.6 ± 18.2 years; BMI: 25.7 ± 5.6 kg/m²) undergoing intubation replacement surgery with GA. Group 3: 47 patients (age: 54.6 ± 32.0 years; BMI: 30.5 ± 5.6 kg/m²) undergoing intubation replacement surgery with GA. Group 2 & 3 RVM data were collected from a ventilator (Stryker, Airgo, Inc., MA). In Group 3, RVM data were collected from a dedicated capnograph (Capnostream 20, Covidien, Mansfield, MA). In Group 1 & 2, RVM data were collected from ET tubes in Groups 2 and 3, respectively, inserted into a tracheostomy. A Deming regression was used to quantify the relationship (sensitivity) between EtCO₂ and MV for each patient. The slope of the regression was presented as an angle from the x-axis. EtCO₂ sensitivity and mean EtCO₂ values were compared across cohorts using an unpaired t-test.

Results

The sensitivities are as follows: in the Left box (Group 1, GA; ET tube): -40.5 ± 9.7° (mean ± SD); Middle box (Group 1, SA; sampling nasal cannula): -53.7 ± 48.0°; Right box (Group 3, awake volunteers, sampling nasal cannula): -50.7 ± 16.1°. Figure 3 shows that in the non-intubated patients, the distribution of sensitivity is unimodal that suggests uniformity within each of the two groups. As shown in Figure 3B, measured EtCO₂ values were systematically higher in Group 1 patients than in Group 2 and 3 patients (31.2 ± 4.4 mmHg vs 25.0 ± 5.2 mmHg vs 31.4 ± 4.0 mmHg, respectively, p<0.001). Figure 3B shows that ECO₂ measurements were normally distributed in all three groups. ECO₂ measurements for the SA intubated patients were significantly higher than those of the other two groups. The SA non-intubated patient had the lowest average ECO₂ measurements out of all 3 groups.

Conclusions

All patients (both intubated and non-intubated) should be monitored for respiratory compromise both before and during surgery. ECO₂ offers a good solution for ventilatory monitoring in intubated patients because of its high sensitivity to changes in MV in that setting.

References: 1 van Loon K, A&A 2014; 119

Figure 1: A non-invasive Respiratory Volume Monitor (RVM) employed in this study. The arrows indicate the continuous, real-time, non-invasive measurements of MV, VT, and RR. Figure 1 shows standard electrode placement. One electrode is placed at the sternal notch, another is placed on the xiphoid and the third is placed in the midclavicular line. Figure 2 shows that across all groups, ECO₂ was negatively correlated with MV. ECO₂ increased, directly correlated with MV. The magnitude of change in ECO₂ was larger in ECO₂ compared to MV (Table 1). A non-parametric correlation test (Spearman’s rank) was performed to determine the relationship between ECO₂ and MV and EtCO₂. The sensitivities are as follows: in the Left box (Group 1, GA; ET tube): -40.5 ± 9.7° (mean ± SD); Middle box (Group 1, SA; sampling nasal cannula): -53.7 ± 48.0°; Right box (Group 3, awake volunteers, sampling nasal cannula): -50.7 ± 16.1°. Figure 3 shows that in the non-intubated patients, the distribution of sensitivity is unimodal that suggests uniformity within each of the two groups. As shown in Figure 3B, measured EtCO₂ values were systematically higher in Group 1 patients than in Group 2 and 3 patients (31.2 ± 4.4 mmHg vs 25.0 ± 5.2 mmHg vs 31.4 ± 4.0 mmHg, respectively, p<0.001). Figure 3B shows that ECO₂ measurements were normally distributed in all three groups. ECO₂ measurements for the SA intubated patients were significantly higher than those of the other two groups. The SA non-intubated patient had the lowest average ECO₂ measurements out of all 3 groups.

Figure 4: Distribution of the average EtCO₂ across groups. (A) Intubated patients, basal values. (B) Non-intubated patients, basal values. (C) Awake volunteers, basal values. (D) Comparison across groups. As shown in Figure 3A, the overall sensitivity is much lower in Group 3 (in Group 1).

Figure 5: Example correlations between MV and ECO₂ in an anesthetized and awake patient. Each data point represents a single 30-sec measurement pair (MV and ECO₂) and the line and confidence ellipse shown the best-fit (Deming regression) ± 1 SD to the data. Steep lines (with slope angles near -90°) correspond to high fidelity (Deming regression) ± 1 SD to the data. Steep lines (with slope angles near -90°) correspond to high sensitivity, i.e. small changes in MV result in large changes in EtCO₂. Flatter lines (near 0°) correspond to low sensitivity, i.e. small changes in MV would not change EtCO₂ much. As seen, ECO₂ is more sensitive to changes in MV in non-intubated patients. When MV increased, EtCO₂ increased. The smaller changes in MV resulted in the larger ECO₂ changes for GA patients.

Figure 6: Distribution of the average EtCO₂ across groups. (A) Intubated patients, basal values. (B) Non-intubated patients, basal values. (C) Awake volunteers, basal values. (D) Comparison across groups. As shown in Figure 3A, the overall sensitivity is much lower in Group 3 (in Group 1).