Using Respiratory Volume Monitoring to Identify Respiratory Compromise in High Risk Obstetric Patients

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Introduction: Current modalities used to identify Respiratory Depression (RD) include Pulse Oximetry (SpO_2), Capnography (Capno, comprised of $EtCO_2$ and respiratory rate - RRcap) and clinical assessment. These are all indirect measurements and therefore late indicators of RD. Respiratory Volume Monitoring (RVM) provides a direct quantitative measure of ventilation in non-intubated patients and has demonstrated effectiveness in identifying RD in post-operative patients following general and orthopedic surgery. The current study evaluates the utility of RVM monitoring in post-partum patients while minimizing nuisance alarms when compared to SpO_2 and Capno.

Methods: In this this IRB approved observational study we enrolled high risk parturients receiving neuraxial opioids during scheduled cesarean delivery with a BMI > 35 kg/m^2 and at least one of the following risk factors: pre-eclampsia, gestational hypertension, diabetes, OSA. MV was measured by RVM (ExSpiron1Xi, Respiratory Motion Inc, Watertown, MA) and presented as a % of predicted MV (MV_{PRED}) based on a body surface area formula. RD was defined as MV< 40% MV_{PRED} for ≥ 2min ("LowMV"). Capno and SpO_2 were measured by the same monitor (LifeSense, Nonin Medical Inc, Plymouth, MN), with Capno alarms set at $EtCO_2$ < 15 and > 45 mmHg, RRcap < 8 and > 30 and SpO_2 alarm set at < 90%, in keeping with standard practice. All technologies delivered an audible alarm as an indication of RD. The protocol encouraged RVM, SpO_2 and Capno to all be measured continuously and for nursing staff to respond to alarms. Alarm rates were compared across the three monitoring modalities.

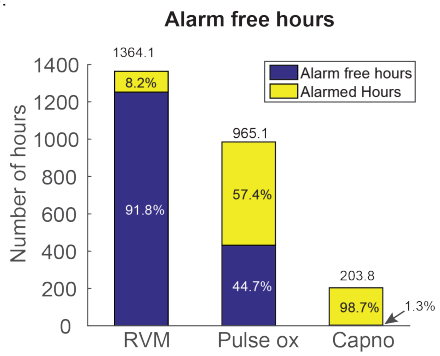
Results: 77 patients (age: 31.7 ± 5.6 yrs; range: 20 – 43 yrs; BMI: 45.9 ± 7.5 kg/m^2, range: 33.5-69.1 kg/m^2) were monitored with RVM for 17.7 ± 4.8 hours (range: 1.7-25.4 hrs), SpO_2 12.7±5.1 hours (range: 0.7-21.9 hrs) and Capno 4.6 ± 3.7 hours (range: 0-14.6 hrs). $EtCO_2$ monitoring was often discontinued due to false alarms or patient non-compliance; 33 patients refused capnography monitoring after initial attempts to place nasal cannula. 37.6% of monitored patients (29) had true RVM alarms due to RD which were generally resolved by the monitor alarm noise or the nurse stimulating the patient. 5 patients had episodes with true SpO_2 alarms. Only one patient had true high $EtCO_2$ alarms. RVM had 5 false alarms due to padset misplacement across all patients, with a false alarm rate of 0.0037 false alarms/hr, significantly lower than SpO_2 4.85 false alarms/hr or Capno 23.48 false alarms/hr ($p < 0.001$, ANOVA).

Conclusions: RVM provided useful respiratory data in post-partum patients and generated actionable alarms. Here we confirmed that monitoring technologies such as pulse oximetry and capnography produce excessive alarms that contribute to alarm fatigue, with 5 and 23 false alarms per hour, respectively. Conversely, a nurse caring for 4 patients monitored by the RVM would experience only 1 false alarm every 2 weeks. High false alarm rates and low sensitivity of other monitoring technologies reduce their utility in the clinical setting to identify important respiratory depression events. Furthermore, alarm fatigue can lead to patient and sometimes staff non-compliance with monitoring technology. Here, we show that the RVM had a greater rate of patient and staff compliance compared to pulse oximetry and capnography, the latter of which was not tolerated by nearly half of the patients.. As such, RVM has the potential to improve patient safety without a negative impact on workflow while decreasing alarm fatigue.

A.

	RVM	Pulse Oximetry	Capnography
Patients	77	77	77*
Monitored Hours/ Study Hours (%)	1364/1567 (87%)	965/1567 (62%)	203/1567 (13%)
Alarm-free hours (% of Monitored Hours)	1251 (92%)	431 (44.7%)	3 (1.8%)
Average time between false alarms	271 hrs	12.5 min	2.6 min

B.



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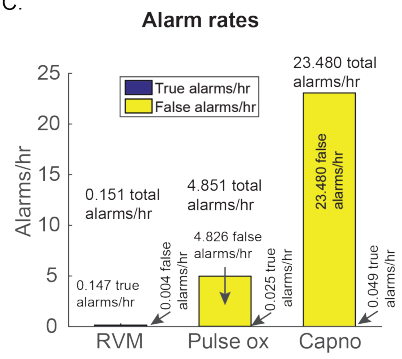

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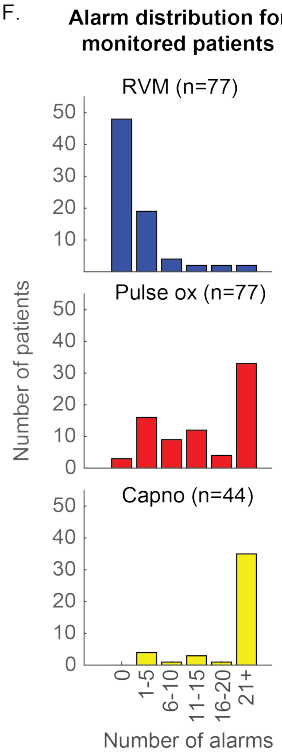

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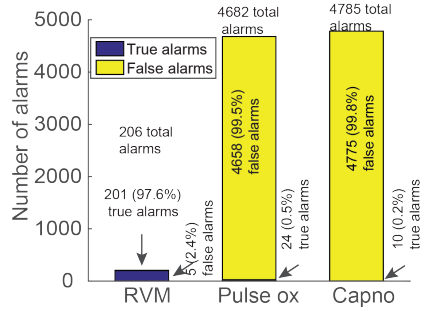

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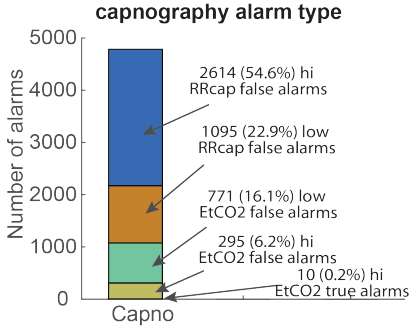

A. Table of monitoring times for RVM, pulse oximetry, and capnography. "Study hours" is the total duration that any one or more of the three physiologic study modalities were in use. "Monitored hours" is the fraction of the study time that the device was acquiring physiological values. Alarms were defined as: 1) RVM: true alarms as MV < 40% of MVpred for ≥ 2 min with false alarms generally caused by padset misplacement, 2) SpO2: true alarms as pulse ox < 90% for ≥ 5 min, with false alarms generally due to intermittent probe dislodgement, 3) Capnography: true alarms as RR < 8 or > 30 (≥ 30s) and as EtCO2 <15 or > 45 mmHg for ≥ 2 min, with false alarms likely due to nasal cannula dislodgement. **B.** Alarm free hours are the number of monitored hours between each alarm. **C.** Alarm rates are calculated by the number of alarms divided by monitoring hours, for each monitoring technology and alarm type (total, true, and false alarm rates). **D.** Number of alarms for each monitoring technology. **E.** Capnography alarms are further separated into each alarm category. Number of alarms and percentage of total alarms are presented. **F.** Distribution of patients with specific number of alarms for each monitoring technology. RVM had a greater number of patients (48/77 patients) with no alarms compared to SpO2 (3/77 patients) and Capno (0/44 patients). *33 patients refused capnography monitoring due to discomfort, after initial attempt to place cannula.