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Original contribution

Respiratory volume monitoring in an obese surgical population and the prediction of postoperative respiratory depression by the STOP-bang OSA risk score☆,☆☆,★,★★,☆☆☆

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Abstract

Study Objective: To evaluate use of a respiratory volume monitor (RVM; ExSpiron, Respiratory Motion, Inc., Waltham, MA, USA) that provides minute ventilation (MV), tidal volume (TV) and respiratory rate (RR) measurements in obese surgical patients, hitherto undescribed.

Design: Prospective, IRB-approved observational study of RVM parameter accuracy in obese surgical patients, designed to test the ability of the RVM to detect predefined postoperative respiratory depression (PORD) and apneic events (POA) and to correlate STOP-Bang scores with PORD and POA.

Setting: Pre-, intra-, and post-op patient-care areas, including the post-anesthesia care unit (PACU) in 2 academic centers with bariatric populations.

Patients: 80 patients (47 ± 12 years), BMI of 43 ± 7 kg/m^2 undergoing elective surgery were enrolled.

Interventions: Data collected included patient characteristics, STOP-Bang scores and RVM data from immediately preoperatively through PACU completion without effecting standard clinical care.

Measurements: Low minute ventilation (LMV) was defined as 40% of predicted MV, and PORD was defined as sustained LMV for 5 minutes. Appropriate parametric and non-parametric statistical analyses were performed, $P < .05$ considered significant.

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★ Diane Ladd is on faculty at the University of West Virginia and a part time employee of Respiratory Motion, Inc., Waltham, MA, USA.

★★ Study registration at: www.clinicaltrials.gov -NCT 01825278.

☆☆☆ None of this material has been published elsewhere or previously apart from presentation of aspects of this study as abstracts at the 2014 International Anesthesia Research Society (S234, S242, S315) and American Society of Anesthesiologists (A1012) annual meetings.

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Main Results: In 56 patients with complete intraoperative ventilator data, correlation between RVM and ventilator MV measurements was r = 0.89 (measurement bias 1.5%, accuracy 11%). Measurement error was 0.13 L/min (95% confidence interval − 0.93 L/min - 1.20 L/min). In PACU, 16.3% and 31% of patients had PORD and POA respectively. There were no significant differences in the incidence of PORD and POA in 3 STOP-Bang risk categories (P > .2).
Conclusions: There was excellent correlation and accuracy between the RVM and ventilator volumes in obese surgical patients. A considerable number of patients exhibited PORD and POA in the PACU. The STOP-Bang risk scores correlated poorly with PORD and POA which suggests that obese surgical patients remain at risk for early post-operative respiratory events irrespective of the STOP-Bang score.

1. Introduction

In the general surgical population, postoperative pulmonary complications often prolong hospital stay and can be as costly as cardiovascular, infectious or thromboembolic events [1]. Because of the high prevalence of undiagnosed sleep disordered breathing in obese patients, obesity is considered a risk factor for postoperative respiratory compromise [2]. Some institutions have developed perioperative care protocols for such patients, sometimes requiring a prolonged post-anesthesia care unit (PACU) stay, continuous positive airway pressure (CPAP) treatment or enhanced monitoring following PACU discharge [3,4]. The American Society of Anesthesiologists' (ASA) practice guidelines for the perioperative care of patients with obstructive sleep apnea (OSA) recommend the development of such institutional pathways [5].

Although overnight polysomnography (PSG) is considered the gold standard for diagnosis of sleep disordered breathing, this is often impractical, costly, subject to poor patient compliance and the evidence supporting its ability to accurately predict outcomes during postoperative recovery remains elusive [6,7]. As an alternative to identify surgical patients at risk for OSA, questionnaire-based tools have been developed. One such validated instrument that offers preoperative OSA risk-stratification based on demographic and anthropomorphic characteristics is the STOP-Bang questionnaire [8].

An FDA-cleared non-invasive respiratory volume monitor (RVM) is available that provides continuous, real-time measurements of minute ventilation (MV), tidal volume (TV) and respiratory rate (RR) in spontaneously breathing patients. Although the RVM has been validated and employed in the PACU in a general surgical population [9,10], it has not been specifically tested in an obese surgical population.

Thus, the three-fold pragmatic, clinically relevant aims of this study were firstly, to define the RVM's accuracy in an obese surgical population; secondly, to determine the ability of the RVM to detect predefined postoperative respiratory depression (PORD) and apnea (POA); and thirdly, to investigate the association of STOP-Bang scores and/or a preoperative PSG OSA diagnosis with these pre-defined PORD and POA events in the PACU.

2. Materials and methods

This was an IRB approved, prospective observational study conducted in two academic medical centers in the United States. Following written informed consent, obese (BMI > 35 kg/m^2) participants, aged 18 years and older undergoing elective bariatric or general surgical procedures from April 2013 to June 2014 were enrolled. Bariatric surgical procedures were all conducted laparoscopically. The intra- and postoperative care remained at the discretion of the anesthesia and clinical care teams who were not involved in, and were blinded to the study data, as the device display remained obscured during the study period. No study specific anesthetic or recovery pathways were applied. Data collected included patient characteristics, medical history, PSG confirmed OSA diagnosis (apnea/hypopnea index >5), STOP-Bang scores and anthropometrics. This study was registered at www.clinicaltrials.gov under NCT 01825278.

2.1. Study protocol

Subjects were monitored with an impedance-based RVM (ExSpiron, Respiratory Motion, Inc., Waltham, MA, USA). Digital respiratory traces and MV, TV, and RR measurements were recorded via a three-electrode PadSet placed on the chest per manufacturer instructions (10). Data collection began in the preoperative holding area, continued during surgery and throughout the PACU stay. Clinical care providers and research staff were blinded to the RVM measurements.

In the operating room OR), the RVM was synchronized with the anesthesia ventilator (Draeger Apollo®, Draeger, Telford, PA., USA) over a single 30-second period prior to the start of surgery. Synchronization was undertaken during controlled ventilation, on stable ventilator settings, with no surgical activity or patient manipulation. Two additional 30-second RVM and ventilator recording segments were selected post-hoc during stable surgical and ventilation conditions at the beginning and the end of the operation to validate the accuracy of RVM measurements.

2.2. Definition and identification of low minute ventilation

An objective MV threshold to define low MV or respiratory depression has not been determined. Although 100 ml/kg^{-1}/min^{-1} (predicted body weight) has been assumed to predict normocapnea, estimation may be inaccurate in obese patients. The landmark ARDSnet protocol required a minimum TV of 4 cc/kg^{-1} for extubation [11]. By using this TV with a defined minimum normal RR of 10/min^{-1}, the calculated MV would be approximately 40% of the predicted MV, with which we defined the conservative threshold of 40% of predicted MV as "Low MV". We assessed the lowest MV (5-minute average) for each patient in the PACU, and defined PORD as sustained Low MV (LMV) for =5 minutes.

2.3. Assessment of postoperative respiratory depression and apnea

Aligning with standard definitions from sleep medicine, an apneic event (AE) was defined as no detected breaths by the RVM for >10 seconds. A patient was considered to have postoperative apnea (POA) if there were >5 AE/hour over the entire PACU stay. Three different binary classification models based on either STOP-Bang risk stratifications (SB) or PSG confirmed diagnosis of OSA as predictors for POA were tested. The first model compared patients with low SB score (0–2) versus patients with intermediate and high SB scores (3–8), the second compared low and intermediate SB scores (0–4) versus high SB scores (5–8), and the third compared patients with PSG confirmed diagnosis of OSA versus patients with no known OSA diagnosis. Correlation of POA with PORD and the predictive capability of POA for the development of PORD were also analyzed. To mimic current clinical practice, preoperative PSG data was noted when available, but was not a part of the study protocol. End-tidal CO2 monitoring was not used in the PACU.

2.4. Statistical analyses

Linear regression and Bland–Altman analysis [12] were employed to compare RVM and ventilator measurements. Because of the observational nature of this study and a paucity of published data to generate a hypothesis, we were not able to determine a sample size a priori. Multi-factor ANOVA was used to evaluate differences in patient characteristics between groups that manifested different respiratory outcomes. For comparison of the incidence of POA and PORD between groups, the two-tailed Fisher's exact test was used. Significance was set at $P < .05$. Conventional sensitivity and specificity analyses were applied to evaluate the predictive abilities of the proposed classification models. All analyses were performed in Matlab R2012b (Mathworks, Natick, MA, USA). Data are presented as mean ± SD unless otherwise stated.

3. Results

Eighty subjects (55 females) aged 47 (±12) years with an average BMI of 43 (±7) kg/m^2 were enrolled. All patients underwent elective bariatric or general surgical procedures under general anesthesia with controlled ventilation.

3.1. RVM and anesthesia ventilator synchronization and comparison

Fifty-six patients (39 females) aged 50 ± 14 years with a BMI of 44 ± 8 kg/m^2 had complete intraoperative ventilator data for comparison with the RVM, with a mean RVM and ventilator recording time of 153 ± 33 min. Fig. 1 shows a sample trace of a patient. In twenty-four patients early in the study, technical difficulties prevented complete intraoperative ventilator data collection and RVM data acquisition for this part of the study, and were not included in this part of the analysis.

Correlation coefficients at the beginning and end of the case between the RVM and ventilator traces were >0.95 (Pearson correlation) and across the entire cohort was 0.89 (Fig. 2). Average measurement bias between the devices was 1.5%, with an average precision and accuracy of 11%. The mean Bland–Altman measurement error was 0.13 L/min with a 95% confidence interval (CI) between −0.93 L/min and 1.20 L/min.

3.2. Postoperative respiratory depression and apnea

Using PACU RVM recordings from all 80 participants, 25 (31%) and 13 (16.3%) met our pre-defined POA and PORD criteria respectively. There were no statistically significant differences in the incidence of POA and PORD among patients in the three STOP-Bang OSA risk categories, and the same was true for patients with and without PSG confirmed OSA (Table 1, Fisher exact test, $P > .2$, for all). Analysis in the three binary classification models (Table 2) showed that using the STOP-Bang risk score or PSG-confirmed OSA as a predictor of POA did not result in clinically useful sensitivity, specificity, positive predictive values (PPV) or negative predictive values (NPV).

Although the first model (STOP-Bang: low vs. intermediate + high scores) had a sensitivity of 88%, specificity was only 16%. The PPV and NPV for all three models were below 40% and 80% respectively. Using the same three models to identify patients with PORD yielded similar results (Table 2). There was also no clinically useful correlation between the STOP-Bang risk score as a continuous variable and POA or PORD in our study population (Fig. 3: A and B). POA did not correlate well with PORD ($r = 0.14$, Pearson correlation). Outcomes of a binary model to predict PORD based on POA are summarized in Fig. 4. Of 13 patients with PORD, 7 had POA and 6 did not (54% sensitivity), and of 25 patients with POA, 7 had PORD and 18 did not (28% PPV).

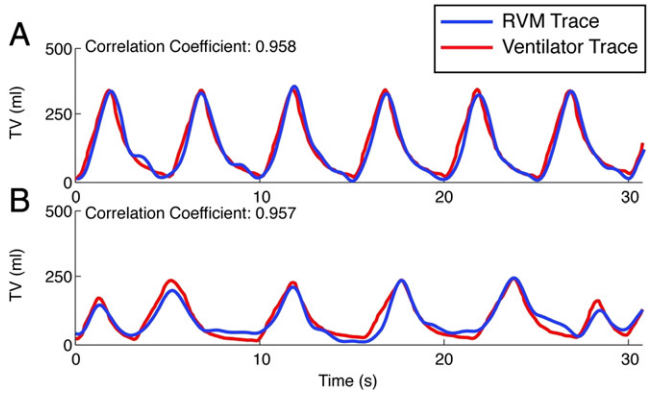

Fig. 1 Representative traces from a patient showing correlation between the ventilator (red) and the RVM (blue).Correlation at the beginning (A) and end of the case (B) 83 minutes later are nearly identical ($R^2 > 0.95$). TV = tidal volume, RVM = respiratory volume monitor.

4. Discussion

Results of the analysis of those subjects with complete intraoperative ventilator data demonstrate an excellent correlation between the RVM and measured anesthesia ventilator volume, providing clinically relevant accuracy in a morbidly obese surgical population, acknowledging the potential variability of ventilator data introduced by ventilator and breathing circuit compliance. These findings extend previously reported observations in frail, normal and overweight patients [13,14].

In the entire study cohort, 16.3% were identified to have PORD using the conservative study definition extrapolated from ARDS-Net tidal volume safe extubation thresholds, and 31% exhibited postoperative apneic events. In a population at risk for PORD and POA, which in our cohort included severely obese patients, the ability to identify PORD and POA postoperatively with objective data from the RVM could potentially impact clinical care pathways for this group of patients. Placing obese patients on a specific pathway to prevent respiratory complications with the ability to accurately assess ventilatory status postoperatively seems desirable, and real time RVM measurements in the perioperative period may enable the individualization of patient care.

Morbidly obese patients often present with undiagnosed OSA and remain at presumed risk for PORD and POA. The STOP-Bang score was not originally designed to identify patients at risk for PORD and POA, but rather risk-stratify

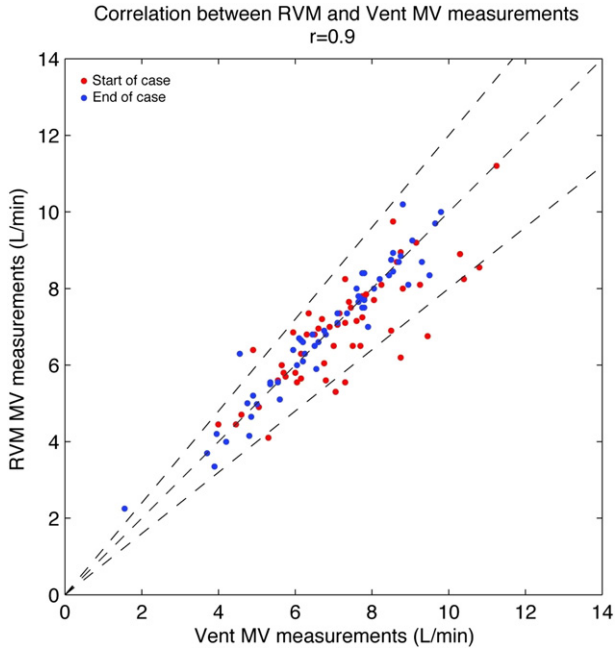

Fig. 2 Correlation of corresponding minute ventilation measurement pairs from the respiratory volume monitor.Each patient contributed two data points to this minute ventilation plot, each based on a 30-second respiratory segment: beginning of surgery (red) and end of surgery (blue). RVM-MV = respiratory volume monitor minute ventilation, Vent-MV = Anesthesia ventilator minute ventilation, L/min = liters per minute.

Table 1 Association of STOP-Bang score and PSG-OSA diagnosis with postoperative apnea and postoperative respiratory depression

RVM result	STOP-Bang risk classification				PSG – OSA diagnosis		
	Low (0–2)	Intermediate (3–4)	High (5–8)		OSA -	OSA +	
	n = 12	n = 25	n = 43	*p*- value	n = 51	n = 29	*p*- value
POA +, n(%)	3 (25)	5 (20)	17 (40)	0.24	16 (31)	9 (31)	1.00
PORD +, n(%)	2 (8)	3 (12)	8 (19)	0.91	7 (14)	6 (20)	0.53

The percentage of postoperative apnea (POA) was similar among patients with low, intermediate and high STOP-Bang scores and among those with or without out a PSG-OSA diagnosis. Similarly, the incidence of postoperative respiratory depression (PORD) among groups was not different (Fisher's exact test). PSG = polysomnogram, RVM = respiratory volume monitor, OSA = obstructive sleep apnea.

patients for the presence of OSA under more normal conditions [8]. In our study, we examined the possible correlation of preoperative STOP-Bang risk score with PORD and POA in the PACU and tested several prediction models. Interestingly, we were unable to demonstrate a meaningful correlation between the STOP-Bang score and either PORD or POA in the PACU. The same result was found when using a PSG-confirmed OSA diagnosis, indicating that a diagnosis of OSA per se did not reliably predict either POA or PORD in the PACU. Furthermore, we did not find a clinically useful correlation between PORD and POA in the PACU. Although PORD and POA could be perceived as a clinical continuum, our results suggest that these events may be separate entities, and POA may not directly predict PORD.

Potential limitations of this study include the relatively small sample size in the absence of an a priori power analysis, the finite period of monitoring confined to the patient's surgery and PACU stay, lack of uniform preoperative PSG or use of postoperative $ETCO_2$. In addition, early during the study, technical difficulties with intraoperative data acquisition causing greater than anticipated drop-out for the first part of the study. Correlations of PORD and POA events with additional clinical parameters including oxygen saturation and arterial pCO_2 would have been desirable and should be addressed in future studies. Although the study was conducted in a standard care setting, the possibility of a Hawthorne effect by the presence of an additional patient monitoring device resulting in a reduced PORD and POA incidence in the PACU could not be completely excluded.

Nonetheless, our results suggest that further investigation of this monitor beyond the immediate postoperative phase appears to be warranted. Given the absence of clinically validated definitions of low MV and PORD, the parameters used in our study appear clinically reasonable and suitable to this trial, yet require further confirmation in practice. Likewise direct correlation of RVM monitoring and clinical outcomes is needed, and should be pursued.

In conclusion, the RVM is accurate in an obese surgical population. Applying a conservative study definition, a considerable number of obese patients with PORD and POA can be identified. PORD and POA are not necessarily predictive of each other and appear to be separate entities. Neither the STOP-Bang risk score nor PSG-confirmed OSA was useful in the prediction of PORD or POA in this study. Based on our data, the RVM has potential impact for patient care. Its role in providing useful treatment guidance and improving perioperative outcomes needs to be further studied.

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Table 2 SB score and PSG-OSA diagnosis as predictors of postoperative apnea and postoperative respiratory depression

SB cut offs as POA predictors	True pos	False pos	False neg	True neg	Sensitivity (%)	Specificity (%)	PPV	NPV
3 (low vs intermediate + high)	22	46	3	9	88.0	16.4	32.4	75
5 (low + intermediate vs high)	17	26	8	29	68.0	52.7	39.5	78.4
PSG-OSA as predictor of POA	9	20	16	35	36.0	63.6	31.0	68.6
SB cut offs as PORD predictors								
3	11	57	2	10	84.6	14.9	16.2	83.3
5	7	36	6	31	53.8	46.3	16.3	83.8
PSG-OSA as predictor of PORD	6	25	7	44	46.2	63.8	19.4	86.3

Legend: A predictive model to identify patients with postoperative apnea (POA) and postoperative respiratory depression (PORD) as determined by the respiratory volume monitor, based on the STOP-Bang (SB) score is not able to minimize Type I and Type II errors simultaneously and various SB cut-off values yield either high sensitivity with low specificity or vise-versa. Pos = positive, neg = negative, PPV – Positive Predictive Value; NPV – Negative Predictive Value. OSA = obstructive sleep apnea, vs = versus, PSG = polysomnogram.

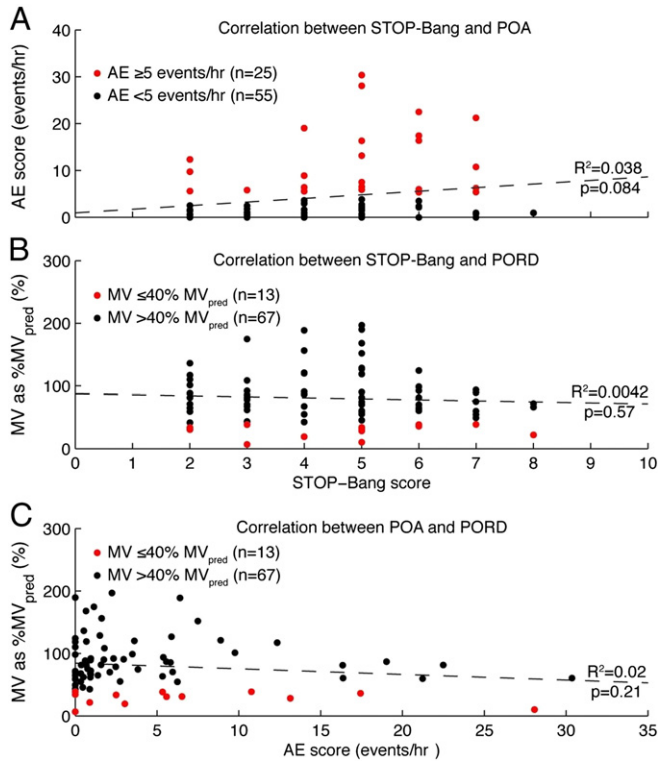

Fig. 3 Correlations between postoperative apnea (POA), and postoperative respiratory depression (PORD), and STOP-Bang scores as continuous variables.(A) Correlation between STOP-Bang score and POA (as average apneic events/hour). (B) Correlation between STOP-Bang score and lowest minute ventilation (MV) in the post-anesthesia care unit (as % of predicted). (C) Correlation between POA and low MV. Combination of the data presented in (A) and (B). MV = munite ventilation, pred = predicted, AE = apneic events, hr. = hour, POA = postoperative apnea, PORD = postoperative respiratory depression.

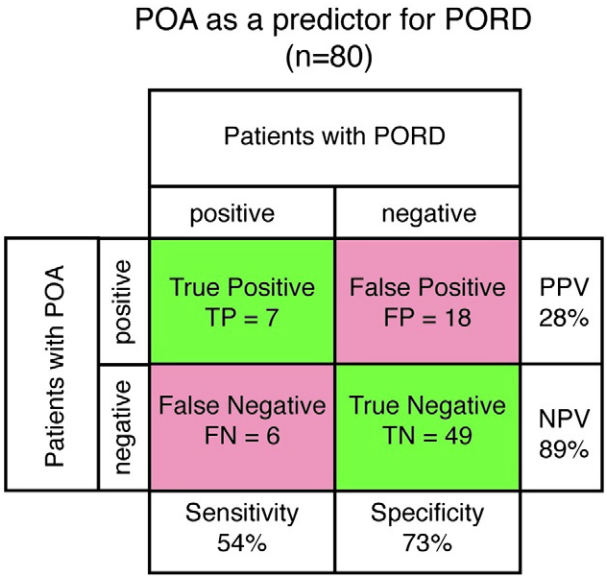

Fig. 4 POA as a predictor of PORDPatients were stratified according to the presence of postoperative apnea (POA). In each sub-group, patients with postoperative respiratory depression (PORD) were identified. TP = true positive, FP = false positive, PPV = positive predictive value, NPV = negative predictive value.

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