Monitoring anesthesia: Optimizing monitoring strategies to reduce adverse effects of anesthetic drugs on ventilation

Broens, S.J.L.

Author: Broens, S.J.L.
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CHAPTER 6

Recognition of respiratory compromise-related postoperative respiratory events with the Integrated Pulmonary Index algorithm

Suzanne Broens, Albert Dahan, Monique van Velzen

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Introduction

Respiratory compromise can be defined as a state in which there is a high likelihood of decompensation into respiratory insufficiency, respiratory failure or arrest, when early identification and intervention may prevent further deterioration(1). Respiratory compromise is a primary cause of postoperative complications, often leading to intensive care unit admission and increased risk of brady-tachyarrythmias and cardio-respiratory arrest(2). In addition to impaired central drive due to peri-operative opioid analgesia, certain patient comorbidities are associated with increased risk of respiratory compromise.(3-5). These comorbities include, but are not limited to: age ≥ 65 years, obstructiuve sleep apnea, chronic obstructive pulmonary disease, bronchoconstriction, idiopathic pulmonary fibrosis, pulmonary embolism, congestive heart failure, acute postoperative renal failure, diabetes, coronary artery disease and hypertension(3-5).

Rapid recognition of respiratory events in the immediate postoperative period can reduce the risk or prevent progression of respiratory compromise. However, spot checks of respiratory rate and peripheral capillary oxygen saturation (SpO_2) – a common care standard for monitoring patients – do not provide adequate clinical assessment of ventilatory status(6), leaving the patient unmonitored over 95% of the time(7), and recent literature on the incidence of postoperative respiratory events would appear to justify an enhanced patient monitoring protocol. For example, one study designed to quantify postoperative respiratory events (bradypnea and apnea) and the risk factors for these events in 68 patients ≥60 years showed that almost 80% of the patients experienced at least one bradypneic period during the 6-hour postoperative period and almost 60% had at least one apnea event(8). Patients with apnea had significantly larger neck circumferences than did those without apnea(8). These results suggest that continuous respiratory monitoring of patients is warranted on the ward after transfer from the PACU, particularly for patients with risk factors such as opioid administration and a larger neck circumference(8).

Continuous monitoring of oxygenation and ventilation using pulse oximetry and capnography, respectively, allows clinicians to identify trends in respiratory parameters not captured by intermittent monitoring and promotes timely medical intervention that may prevent respiratory arrest. The Integrated Pulmonary Index ™ (IPI) algorithm utilizes an artificial intelligence algorithm that combines the real-time measures of four parameters (i.e., multiparametric) – end-tidal CO_2 (ET_{CO2}); respiratory rate; pulse rate; and SpO_2 – into a single, easy-to-use 1-10 scale to provide an indication of changes in patients' ventilatory status(9-10). Table 1 shows interpretive criteria. Lower numbers represent poorer respiratory status. Ten is considered normal; values between one and four reflect critical events that require intervention.

Table 1. IPI Patient Status Scale

	IPI	Patient status
	10	Normal
	8-9	Within normal range
	7	Close to normal range; requires attention
	5-6	Requires attention and may require intervention
	3-4	Requires intervention
	1-2	Requires immediate intervention

Capnography and the IPI algorithm are valuable tools for monitoring patients who may be at increased risk for respiratory compromise following surgery(11-16) and to increase the opportunity for treatment before cardio-respiratory arrest(17). We conducted a study to evaluate the clinical utility of the IPI algorithm for detecting respiratory events in the postoperative patients and to determine the incidence of respiratory events in these patients.

Patients and Methods

Following IRB approval and obtaining informed consent, 40 patients scheduled for elective surgery under general anesthesia were included in the study. Continuous IPI algorithm measurements (data storage frequency 0.5 Hz) using the Capnostream 20p patient monitor (Medtronic) began immediately after admission to the PACU and continued until 8 am of the first postoperative day. Known risk factors for respiratory compromise including sleep apnea and opioid administration were identified for each patient by history and chart review.

Results

Demographic data from the 40 patients are shown in Table 2. One patient discontinued participation due to discomfort with the ET_{CO_2} sampling cannula. The mean age was 57.2 years (range: 31.5 to 75.8) and the mean body mass index (BMI) was 26 kg/m^2 (range: 16.6 to 38.2). The large majority of patients received total intravenous anesthesia and opioid analgesia. The most common surgical procedure was post-mastectomy autologous fat graft.

Table 2. Patient and Surgery Characteristics

Patient Characteristics	
Number of patients analyzed	40
Gender (male/female)	22/18
Age (years)	57.2 ± 12.2 (range: 31.5 – 75.8)
Weight (kg)	80.9 ± 17.4 (range: 54.5 – 135)
Height (m)	1.76 ± 0.1 (range 1.54 – 1.92)
BMI (kg/m^2)	26.0 ± 4.6 (range: 16.6 – 38.2)
Surgery Characteristics	
Duration of anesthesia (min)	277 ± 146 (range 48 - 659)
Type of surgery, n (%)	
General	10 (25)
Nephrectomy	8 (20)
Post-mastectomy autologous fat graft	13 (32.5)
Vascular	4 (10)
Other	5 (12.5)
Type of anesthesia, n (%)	
Total intravenous	35 (87.5)
Balanced	5 (12.5)
Neuromuscular block reversal, n (%)	
None	30 (75)
Neostigmine	2 (5)
Sugammadex	8 (20)
Postoperative pain relief, n (%)*	
None	11 (27.5)
Morphine	26 (65)
Methadone	5 (12.5)
Esketamine	1 (2.5)

*Total greater than 100% because some patients received more than one type of analgesic

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Approximately 700 hours of postoperative IPI algorithm values were obtained, representing a data set of 1,152,427 observations with an average of 17 hours per patient (range: 12 to 22 hours); 5.8% of measurements were missing (e.g., sensor off). Thirty-nine of the 40 patients had at least one critical IPI event (defined as values between 1 and four), three patients displayed low IPI algorithm values during more than 15% measurement time and critical IPI events occurred in 3.6% of all measurements (Figure 1). These findings appeared unrelated to the presence of sleep apnea or opioid administration schedules. Although the critical IPI events likely required caregiver interventions, this was not recorded because the study was observational. Multivariate regression analysis was performed to predict the percentage of critical events from age, gender, BMI and the duration of anesthesia (Figure 2). Age and BMI addes significantly to the prediction. Figure 3 shows graphs of IPI algorithm recordings from three patients, demonstrating different IPI algorithm results. No serious adverse events occurred during the study.

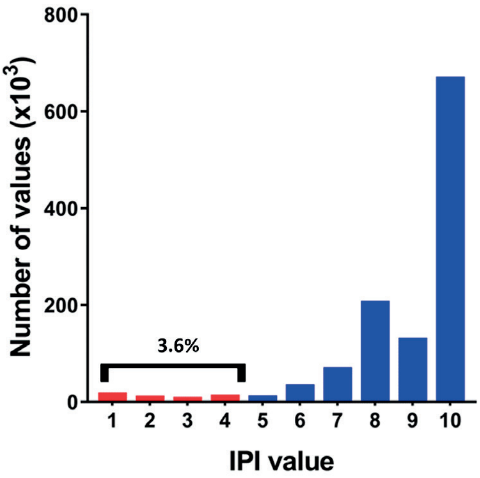

Figure 1. Histogram of observed Integrated Pulmonary Index (IPI) algorithm values. IPI algorithm values were obtained at a 0.5 Hz interval and represent a data set of 1,153,427 observations collected from 40 patients. Critical IPI events, values 1-4, are labeled red

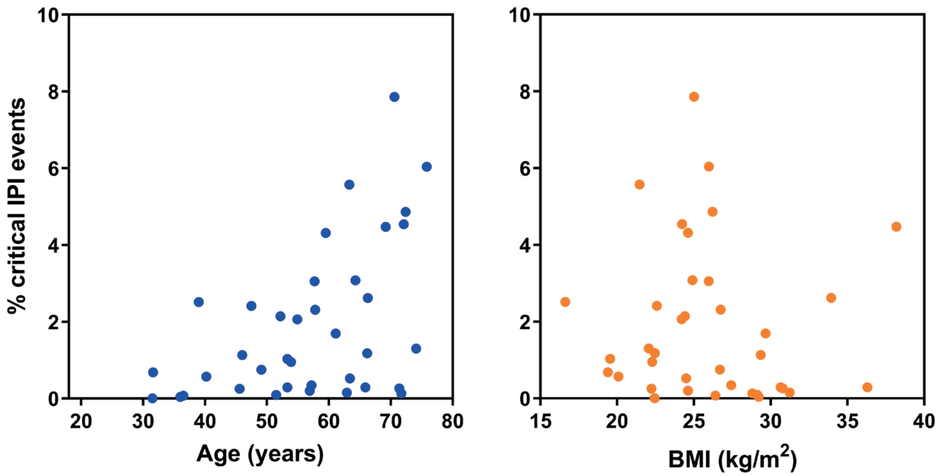

Figure 2. Correlation plots of age (left panel) or BMI (right panel) and percentage of critical IPI events (range 1-4, as percentage of total recording period) per patient. Multivariate regression analysis was performed to predict the percentage of critical IPI events from age, gender, BMI and the duration of anesthesia. These variables predicted the occurrence of critical IPI events, $F(4,32)= 4.523$, $P = 0.005$. More specifically, age and BMI added significantly to the prediction ($P <0.05$).

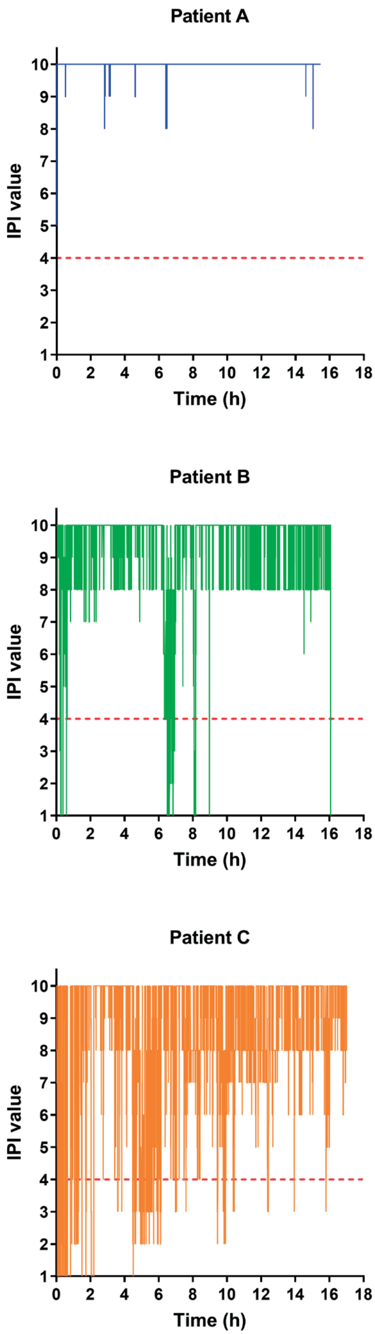

Figure 3. Example graphs of IPI algorithm recordings from three patients. (**A**) During the 17-hour recording period, no critical IPI events were observed. (**B**) Some critical IN events were registered during the 17-hour study period. (**C**) Frequent and prolonged episodes of critical IPI events occurred during the 17-hour recording period. Critical IPI events are defined as values between 1-4; the cut-off is indicated in the graphs with a red dashed horizontal line.

Discussion

This study involved 40 patients with an average age of 57 and an average BMI of 26 kg/m^2 who were scheduled for elective surgery under general anesthesia. Following their respective procedures, most of the patients were provided pain relief with morphine, methadone or esketamine. They were monitored using the IPI algorithm in a postoperative setting for an average of 17 hours. Results from the study showed the IPI algorithm was easy to use and almost all patients displayed at least one critical event, likely requiring intervention. However, critical IPI events and low IPI values appeared to be unrelated to the presence of sleep apnea or opioid administration, which are known risk factors for respiratory compromise. In contrast, older age and higher BMI were significant predictors of critical IPI events.

Conclusion

These results show that critical IPI events are common during the immediate postoperative period and demonstrate the clinical utility of the IPI values for detecting respiratory events in postoperative patients. Based on these results, interventional studies are planned to assess the performance of the IPI values as an early warning sign of respiratory compromise.

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