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CLINICAL REPORT

Effects of A-Line Autoregression Index (AAI) Monitoring on Recovery After Sevoflurane Anesthesia for Bariatric Surgery

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Abstract Monitoring depth of anesthesia may improve anesthetic dosing and postanesthetic recovery in obese patients. Sixty morbidly obese patients undergoing laparoscopic adjustable gastric bandage (LAGB) were randomly assigned to receive anesthesia with sevoflurane titrated by either standard clinical parameters (SCP) (target=baseline hemodynamic parameters±20%) or by A-line ARX index (AAI) (target=20±5). Heart rate, arterial blood pressure, inspiratory and expiratory gas concentrations, and AAI were recorded in all patients at 5-min intervals, but AAI was made available only to the anesthesiologist assigned to AAI-monitored patients. Emergence times in surgery room and recovery times in postanesthesia care unit (PACU) were recorded at 1- and 30-min intervals. Mean intraoperative values of AAI were higher in AAI-monitored than in SCP-monitored patients (22.5 vs 15.0, p=0.001). Compared to SCP monitoring, AAI monitoring reduced consumption of sevoflurane by 20% (p=0.014), times to eye opening by 2.4 min (p=0.001) and to extubation by 2.5 min (p=0.009) and to achieve SpO_2 92% in room air by 17 min (p=0.001). Aldrete scores were higher in AAI- than in SCP-monitored patients at arrival in PACU (p=0.035), but Aldrete scores ≥9 were attained in similar times. AAI monitoring can improve titration of and recovery from sevoflurane for LAGB.

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Introduction

Obese patients are at higher risk of postoperative respiratory complications than normal weight population [1, 2]. Enhancing recovery reduces postoperative complications. Older anesthetics (i.e., halothane and isoflurane) are highly lipophilic and tend to accumulate in fatty tissues during delivery and to diffuse back to the Central Nervous System after delivery is stopped, delaying thus emergence [3, 4]. Newer volatile anesthetics (i.e., desflurane and sevoflurane) have lower lipid solubility and more favorable characteristics of awakening [3, 4]. In obese patients, however, optimization of anesthetic drugs remains a major challenge that can be improved by instrumental monitoring of depth of anesthesia [2–4].

In the last two decades, different neurophysiological techniques have been developed to assess the depth of anesthesia. The bispectral index, the patient state index, and the state entropy are based on processing variables of spontaneous electroencephalogram [5, 6]. The auditory-evoked potential monitor, in contrast, assesses the anesthetic effect by utilizing the middle latency auditory-evoked potentials (i.e., 10–50 ms) that originate from the auditory neuronal pathway in response to a standardized auditory stimulus [6]. Mid-latency potentials are extracted from background electroencephalographic activity using an exogenous input model to generate the auditory autoregression index (AAI) over a numerical range of 0 to 100 [5, 6].

AAI is attenuated in a dose-dependent fashion by most general anesthetics (i.e., enflurane, isoflurane, desflurane,

sevoflurane, propofol, and xenon) [6]. AAI, however, is not sensitive to opioids nitrous oxide or ketamine [6] so that AAI indexes better a hypnotic-based anesthetic technique (i.e., low-dose analgesic plus high-dose volatile anesthetic) rather than a more analgesic-based anesthesia (i.e., remifentanil combined with low-dose hypnotic) [5, 6]. In non-obese patients, AAI monitoring effectively reduced anesthetic consumption and recovery times [7–11], although positive findings have not been confirmed in all studies [12–14]. AAI may provide more consistent advantages in obese than in lean patients because of difficulty in drug dosing in the former [1–5]. The aim of this study was to test the clinical usefulness of AAI monitoring in relation to clinical practice in obese patients undergoing anesthesia with sevoflurane for laparoscopic gastric bandage (LAGB).

Materials and Methods

Subjects

After obtaining IRB approval at the Department of Anesthesiology of Padova University, Italy (ISRCTN 18342801), and written informed consent, 60 consecutive patients undergoing LAGB for morbid obesity [body mass index (BMI) >40 kg m^{-2}] were enrolled in the study. Exclusion criteria were patient age less than 18 years, ASA score >III, history of difficult tracheal intubation requiring fiber optic intubation, any disabling central nervous system or cerebrovascular disease, chronic obstructive lung disease, coronary artery disease and/or myocardial infarction, congestive heart failure, history of allergy to anesthetic drugs including volatile anesthetics, hypersensitivity to opioid or substance abuse, treatment with opioid or any psychoactive medication, myasthenia gravis, or malignant hyperthermia. Enrolled patients were assigned either to the SCP-monitored (control) group or to the AAI-monitored group by using a computer-generated random table.

Study Protocol

Following overnight fasting, patients were taken to the preoperative holding area. An 18–16-gauge IV line was inserted in an arm vein, and an infusion of saline solution was established. Two silver–silver chloride electrodes for auditory-evoked potentials were placed one on the forehead and one behind the left ear over the mastoid bone, and acceptable contact impedance (< 5 kΩ) was confirmed when the electrodes were connected to an AAI monitor (Alaris medical system, version 1.4, Hampshire, UK). Earphones were placed over the patient's ears and connected to the device to provide the auditory stimulus, an intermittent click (9-Hz, 65-dB sound pressure level). AAI was recorded at baseline as a mean of three consecutive readings with the patient's eyes closed for 1–2 min prior to induction of anesthesia. AAI was then taken at 5-min intervals throughout the anesthesia period with recording being interrupted during electrocoagulation and cautery.

Three investigators were involved in each case. The first investigator was the anesthesiologist responsible for administering anesthetic drugs and monitoring the depth of anesthesia. The second investigator was an anesthetist who ensured the proper functioning of AAI monitor throughout the anesthesia and recorded the exact timing of specific events (i.e., skin incision, patient movements, and extubation of trachea) and physiologic and AAI data during the operative period. End-tidal gas concentrations (i.e., oxygen, carbon dioxide, and sevoflurane), heart rate and arterial-pulse oximetry (SpO_2), arterial blood pressure, train-of-four ratio (TOFR) (TOF-watch Organon Teknik, Ireland), and AAI were recorded at 5-min intervals. The AAI monitor was made available only to the anesthetist providing care to AAI-monitored patients. Premedication was done in all patients by an IV bolus of midazolam 0.05 mg kg^{-1}. Anesthesia was induced with intravenously administered propofol 2–3 mg kg^{-1} ideal body weight (IBW) [3, 4] and intravenously administered fentanyl 1–2 μg kg^{-1} IBW. Trachea intubation was facilitated by administration of intravenously administered succinylcholine 1–1.5 mg kg^{-1}. Neuromuscular blockade was maintained with intravenously administered cisatracurium IBW administered as a bolus of 0.15 mg kg^{-1} followed by a continuous infusion at 2 μg $kg^{-1}min^{-1}$. Mechanical ventilation of the lungs was initiated immediately after tracheal intubation (Servo Ventilator 300A, MAQUET Italia, Milan, Italy) using pressure control mode ventilation with tidal volume of 10 mL kg^{-1} IBW, PEEP of 4 cm H_2O, inspiratory–expiratory time ratio of 1:2, inspired oxygen fraction of 0.5, and a total gas flow of 2 $Lmin^{-1}$. Ventilatory rate was set initially at eight breaths per minute and then adjusted to keep an end-tidal CO_2 concentration of 35–40 mmHg. Anesthesia was maintained with sevoflurane given initially at one minimum alveolar concentration (MAC) (i.e., about 2.2%) in oxygen/air mixture (50/50%) through a semi-closed circuit with a carbon dioxide absorber. No specific MAC value was sought. In the SCP-monitored patients, sevoflurane was titrated to maintain heart rate and blood pressure within ± 20% from baseline and to avoid movements, tearing, and sweating. In the AAI-monitored patients, sevoflurane was titrated to maintain a target AAI value of 20±5. If hemodynamic control could not be achieved within 5 min after 0.5% sequential increases of sevoflurane, intravenously administered fentanyl 1 μg kg^{-1} IBW was given. Mean arterial pressures <70 mmHg were treated with intravenously administered crystalloids and,

when necessary, with intravenously administered etilefrine 2 mg and bradycardia (<50 beats/min) with intravenously administered atropine 0.5 mg.

Twenty minutes before end of surgery, patients received intravenously administered 30 mg ketorolac and intravenously administered 4 mg dexamethasone to reduce pain and nausea and vomiting (PONV) in the postoperative period. Simultaneously, the infusion of cisatracurium was stopped. Sevoflurane was discontinued on completion of skin closure, and a fresh oxygen flow was increased to 10 L min^{-1}. Reversal of neuromuscular block was achieved with intravenously administered neostigmine 0.05 mg kg^{-1} IBW and intravenously administered atropine 0.01 mg kg^{-1}. The patient was put in a 30° up Fowler's position and extubated when fully awake with TOFR ≥0.9 and tidal volume >5 mL kg^{-1}. Times of anesthesia were taken from preoxygenation to tracheal extubation and times of surgery from skin incision to closure of the skin. Times to emergence (i.e., opening eyes in response to a verbal command and obeying simple verbal commands) and to tracheal extubation were taken from cessation of sevoflurane. To determine the total consumption of sevoflurane, the vaporizer was filled and weighted before induction and reweighted after completion of anesthesia. The total amount of sevoflurane was calculated using the following formula: volume of used sevoflurane=weight of used sevoflurane/specific weight (1.52 kg L^{-1}). The volume of inhaled sevoflurane was expressed as milliliter per hour.

The third investigator was either an anesthetist or a resident in anesthesiology blind to group assignment who assessed patients in the postanesthesia recovery unit (PACU). SpO_2 was monitored continuously and was recorded along with pain and PONV estimates and Aldrete score [15] at 0, 10, 20, 30, 60, 90, and 120 min after arrival in PACU. Intensity of postoperative pain and PONV was estimated with an 11-point verbal rating scale (i.e., 0, none; 10, worst symptom) and SpO_2 after breathing room air without supplemental oxygen for 5 min [16, 17]. Timing to first "rescue" analgesic and/or antihemetic medications were recorded as well. Finally, at 24 h after surgery, patients were queried about intraoperative events (i.e., presence of explicit memory and dreams). The explicit memory was investigated with the following questions: "What is the last thing you remember before sleeping? What is the first thing you remember after arousal? Did you remember anything between these two moments?" We considered explicit memory to be present if the patients remembered anything that happened between induction of anesthesia and sevoflurane discontinuation.

Statistical Analysis

The primary end-point of this study was defined as the time taken to spontaneous opening of eyes, obeying command, and tracheal extubation. An a priori power analysis estimated that a minimum of 30 patients would be required in each group to detect a difference of 2.5 min with a power of 0.9 (α=0.05). Secondary end-points were sevoflurane end tidal and consumption, and postoperative SpO_2, VAS for pain and PONV, and time to Aldrete≥9.

Statistical analysis used Student's t test, χ^2 test, and analysis of covariance. The relation between sevoflurane end-tidal concentrations and degree of arterial desaturation was analyzed using linear regression to determine the correlation coefficients. Statistical significance was considered at $p<0.05$.

Results

We studied 60 patients elective for LAGB who were randomly assigned to undergo anesthesia with sevoflurane guided either by SCP or by AAI. The two patient groups were similar with respect to demographic and anthropometric characteristics, AAI and hemodynamic values at baseline, and duration of anesthesia and surgery (Tables 1 and 2).

During anesthesia, hemodynamic variables were comparable in the two groups (Table 2). During anesthesia, AAI values were higher on average ($p<0.001$) (Table 2) and less frequently below target range in AAI- than in SCP-monitored patients (27 vs 213 times, $p=0.001$) (Fig. 1). End-tidal concentrations and total consumption of sevoflurane were lower by 18% ($p=0.011$) and 20% ($p=0.014$) in AAI- than in SCP-monitored patients (Table 3). Total doses of propofol, fentanyl, and cisatracurium were not different between groups (Table 3).

After sevoflurane anesthesia and compared to SCP-monitored patients, emergence times in AAI patients were faster to eyes opening by 2.4 min ($p=0.015$) and to tracheal extubation by 2.6 min ($p=0.009$) (Table 3). In PACU, Aldrete scores were higher in AAI- than in SCP-monitored patients, but times to achieve an Aldrete score ≥9 (i.e., a surrogate parameter of discharge from PACU) were not different between groups ($p=0.32$) (Table 3). VAS for pain and PONV were moderate and decreased with time in both groups. Compared to SCP-monitored patients, in AAI-monitored patients, PONV VAS was lower ($p=0.04$) at arrival in PACU, and pain VAS was higher 30 min later ($p=0.05$). AAI- and SCP-monitored groups did not differ in numbers, and times to first administrations of rescue antihemetic drugs (7 and 9 patients, $p=0.56$; 31 and 26 min, $p=0.33$) and analgesic drugs (11 and 8 patients, $p=0.27$; 36 and 43 min, $p=0.38$).

In PACU, SpO_2 oxygen saturation was significantly better in the AAI-than in the SCP-monitored group from arrival ($p=0.0001$) to 60 min later ($p=0.0001$) (Table 4).

Table 1 Patients' demographic characteristics, and anesthesia and surgery times

	Standard clinical practice	AAI-monitored	*p*
Patients (*n*)	30	30	1.000
Male/female (*n*)	8/22	9/21	0.921
Age (year)	38±11	41±11	0.554
Weight (kg)	125±17	127±20	0.502
IBW (kg)	69±6	69±8	0.874
Height (cm)	166±7	166±10	0.924
BMI (kg m^{-2})	45±5	46±6	0.393
Surgery time (min)	63±28	64±26	0.836
Anesthesia time (min)	92±24	89±20	0.684

Values are means±SD. Inter-group comparison by Student *t* test and χ^2 test

AAI auditory-evoked potential index (range 0–100), *BMI* body mass index, *IBW* ideal body weight

Mean time to achieve SpO_2 ≥92% in room air was 17 min shorter in AAI- than in SCP-monitored patients (p=0.002). SpO_2 correlated inversely with BMI (p=0.001), sevoflurane consumption (p=0.028), and end-tidal concentration (p=0.001). Finally, when patients were questioned at 24 h after surgery, dreaming was reported by five SCP- and six AAI-monitored patients. No patient in either group reported recall of intraoperative events.

Discussion

The use of AAI to titrate sevoflurane reduced sevoflurane consumption and recovery times from sevoflurane anesthesia for LAGB. Previous studies on the efficacy of AAI in lean subjects yielded to conflicting results. AAI monitoring failed to impact emergence from anesthesia for knee arthroscopy [12], eye surgery [13], or superficial surgery [14]. In contrast, AAI monitoring reduced volatile gas consumption and recovery times after a 2-h volatile anesthesia for gynecological laparoscopic surgery or for major abdominal surgery [7–10]. AAI monitoring improved also consumption of and emergence from desflurane for spine surgery [11], suggesting that AAI may offer advantages that are more pronounced during longer and deeper anesthesia. Our findings indicate that AAI improves recovery also from a shorter anesthesia with sevoflurane in obese patients.

A prompt recovery from lipophilic anesthetics (i.e., halothane and isoflurane) is limited mainly by the fact that they accumulate in adipose tissues during delivery [3, 4, 18] and diffuse to highly perfused tissues such as the central nervous system after delivery is over [4, 18]. In obese subjects, the mass of adipose tissue amplifies the accumulation and redistribution effect of anesthetics and slows recovery further [3, 4, 18]. This view has been challenged in the case of newer and less lipophilic anesthetics (i.e., desflurane and sevoflurane) by findings that emergence times were similar in lean and obese patients after an anesthesia lasting 2 to 4 h [19, 20]. Nevertheless, postanesthetic recovery has remained an important issue in obese patients because of their high sensitivity to anesthetics and pathological changes in the upper airway muscle, which pose risk of respiratory complications [1, 2].

Table 2 Pre- and intraoperative values of hemodynamics and AAI

	Standard clinical practice	AAI-monitored	*p*
Baseline hemodynamics			
Systolic BP (mmHg)	129±23	131±28	0.573
Diastolic BP (mmHg)	78±13	81±11	0.235
Heart rate (beats/min)	80±3	82±2	0.311
Intraoperative hemodynamics			
Systolic BP (mmHg)	119±12	122±16	0.153
Diastolic BP (mmHg)	68±6	73±7	0.763
Heart rate (beats/min)	71±2	73±2	0.247
AAI (score)			
Awake baseline	93.1±3.0	93.9±4.1	0.415
After induction	12.6±4.6	13.2±3.2	0.847
After incision	19.3±4.5	24.0±3.8	<0.001
Maintenance period	15.0±1.6	22.5±4.7	<0.001
After extubation	71.3±13.9	78.4±15.1	0.043

Values are means±SD. Inter-group comparison by Student *t* test

AAI auditory-evoked potential index (range 0–100), *BP* blood pressure

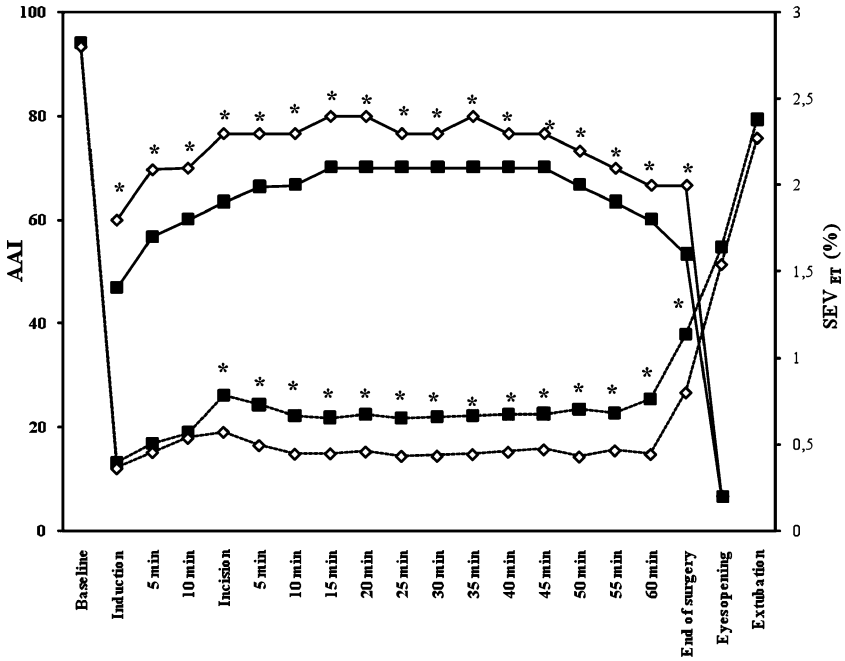

Fig. 1 Sevoflurane end tidal (%, *straight lines*) and AAI (score, *dashed lines*) in SCP- (*squares*) and AAI-monitored patient groups (*diamonds*). Values are presented as means (SD not shown) and compared by Student *t* test. *Asterisks* statistically different ($p<0.05$) from SCP-monitored (control) patients

One approach to improve recovery has been the introduction of drugs that are endowed with short half-life thanks to low lipid solubility (i.e., sevoflurane and desflurane) or rapid blood metabolism (i.e., remifentanil). Short-acting anesthetics have been judged suitable for bariatric anesthesia [19–23]. For an individual anesthetic agent, however, emergence ranges widely from, for example for eye opening after sevoflurane anesthesia, 5 to 19 min [2, 24] depending on administration of other drugs and on method of titration [25]. In fact, the classical SCP method (i.e., monitoring of sympathetic responses to noxious surgical stimuli) is not very reliable for optimization of anesthetic delivery. Neurophysiological monitors of depth of anesthesia have been tested to compare different dosing and features of anesthetics. In direct comparison studies when anesthetic drugs are adjusted to SCP, recovery is more rapid from desflurane than from sevoflurane anesthesia [21, 22]. In contrast, when anesthetics are titrated on AAI or other neurophysiological monitors such as the bispectral index, recovery after desflurane anesthesia is only slightly faster or comparable to recovery after sevoflurane anesthesia [24–28]. Hence, an accurate titration affects recovery substantially and questions the theoretical advantage of short-acting anesthetics [26].

Our study demonstrates that AAI monitoring could improve titration of maintenance anesthetic by reducing the time the AAI value fall below target range. In patients of the SCP control group, AAI values were often below target. In contrast, in AAI-monitored patients, AAI values were more frequently within target range resulting in sevoflurane sparing and faster emergence. It is possible that higher target values of AAI will expedite recovery further [29]. We chose a lower, more conservative, AAI target range (i.e., 20±5) on the base of previous studies [10] and to minimize risk of awareness in patients treated with neuromuscular blocking agents. Tapering off anesthetic

Table 3 Intraoperative anesthetic drug consumption and times of emergence

	Standard clinical practice	AAI-monitored	*p*
Drug consumption			
Propofol total dose (mg)	265±21.7	260±19.4	0.692
Fentanyl total dose (μg)	237±16.6	257±32	0.689
Cisatracurium total dose (mg)	20.3±3.8	21.2±3.0	0.738
$Sevoflurane_{ET}$ (%)	2.2±0.4	1.8±0.3	0.011
Sevoflurane consumption (mLh^{-1})	16.7±5.7	13.3±4.3	0.014
Times of emergence			
To eye opening (min)	14.8±4.8	12.4±4.5	0.015
To obey command (min)	16.2±4.4	13.9±4.9	0.071
To extubation (min)	18.3±5.3	15.7±5.6	0.009

Values are means±SD. Inter-group comparison, Student *t* test

AAI auditory-evoked potential index (range 0–100), *ET* end tidal

Table 4 VAS of pain and PONV, SpO_2, and Aldrete score in PACU

	Standard clinical practice	AAI-monitored	*p*
Pain VAS (0–10)			
Arrival	3.4±1.8	4.3±2.9	0.13
30 min	3.4±1.8	4.4±1.2	0.05
60 min	3.4±2.1	3.3±1.9	0.73
90 min	2.7±1.4	2.6±1.4	0.85
120 min	2.1±0.9	2.0±0.7	0.54
PONV VAS (0 –10)			
Arrival	4.4±1.3	3.7±1.4	0.04
30 min	3.4±0.9	3.3±1.3	0.73
60 min	1.7±0.7	1.9±1.3	0.47
90 min	1.4±0.7	1.7±1.1	0.80
120 min	1.5±0.8	1.5±0.9	0.20
SpO_2 (%)			
Arrival	87.0±4.1	89.1±3.7	0.0005
10 min	87.8±3.5	90.8±2.9	0.0001
30 min	90.8±1.8	93.1±1.7	0.0001
60 min	89.6±2.5	94.2±1.7	0.04
90 min	95.3±1.4	98.9±1.3	0.132
120 min	96.6±1.2	97.0±1.1	0.28
Time to SpO_2 ≥92% (min)	34.7±17.0	17.0±18.5	0.001
Aldrete score in PACU (score)			
Arrival	8.2±0.8	8.6±0.8	0.035
30 min	8.7±0.7	8.8±0.7	0.34
60 min	9.2±0.6	9.5±0.6	0.14
90 min	9.7±0.4	9.7±0.5	0.58
120 min	9.8±0.4	9.9±0.3	0.50
Time to Aldrete score ≥ 9 (min)	38.0±27.2	30.0±32.5	0.32

Values are means±SD. Inter-group comparison, Student *t* test

AAI auditory-evoked potential index; *min* minutes in PACU, when not otherwise indicated; *PACU* postanesthesia care unit; *PONV* postoperatory nausea and vomiting; *VAS* visual analogue scale

toward the end of anesthesia may speed recovery as well [20, 24, 25]. For this study, we chose to discontinue sevoflurane at the end of surgery in order to prevent variable tapering times and rates of decreasing sevoflurane levels from altering emergence times.

A rapid and complete awakening after termination of surgery is highly desirable, because it is associated with earlier maintenance of patent airway, protection against aspiration, and better SpO_2 saturation [7–11, 21]. After sevoflurane discontinuation, however, return to consciousness may require 60 to 90 min to complete [21, 30, 31], during which time it may not be necessarily accompanied by restoration of protective airway reflexes [21]. Residual sevoflurane determines timing of recovery. After its administration ceases, sevoflurane levels decrease rapidly [32], but a 10% tail persists after 1 h [33], and a 5% tail may persist up to 8 h later [32]. Sevoflurane is a general anesthetic and a high-affinity nicotinic receptor antagonist [3, 34, 35]. During recovery, residual sevoflurane and its degradation products may impair chemosensitivity of the Central Nervous System to hypoxia [36] and prolong neuromuscular block by relaxants [37]. The latter effect is especially important in obese patients who often suffer from undiagnosed pathology in the upper airway muscle that makes them vulnerable to postoperative complications [38, 39].

Compared to SCP-monitored patients, AAI-monitored patients had higher SpO_2 saturation from arrival in PACU to 60 min later and were faster to achieve SpO_2 values ≥92% without need of supplemental oxygen. This is, in our view, an important finding, because postoperative oxygen desaturations are frequent in obese patients [2, 3, 17]. Obesity predisposes to airway obstruction and decreased functional capacity and atelectasias [1, 2, 39]. Also, a thoracic or upper abdominal site of surgery [16] and anesthetic drugs [1, 2] worsen risk for postoperative hypoxia. There is an active search to improve postoperative respiratory recovery. Preoxygenation before induction of anesthesia [40], PEEP [41], and recruiting maneuvers [42] during anesthesia and physical therapy after anesthesia [43] have been shown effective to the purpose. Our study suggests that AAI attenuates postoperative respiratory depression substantially by reducing maintenance sevoflurane and, likely, the subsequent residual levels. As a result, obese

patients may benefit from AAI monitoring not only at emergence but, importantly, also during intermediate recovery when they are at high risk of respiratory complications [1, 2].

Consistently with previous evidence, AAI titration of sevoflurane anesthesia did not increase postoperative complaints or recall of intraoperative events [9, 10]. Pain and PONV were moderate and required similar numbers of rescue drugs in the two study groups. No patient recalled intraoperative awareness, and few patients reported dreaming after anesthesia as it typically occurs during recovery when patients are sedated or in a physiologic sleep state [44].

In conclusion, AAI monitoring improved recovery from sevoflurane anesthesia for LAGB.

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