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Predicting postoperative pulmonary complications in high-risk populations

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Abstract

Purpose of review—Our objective is to describe prediction models for surgical patients who have suspected obstructive sleep apnea (OSA) at risk for postoperative respiratory complications and for surgical patients at risk for postoperative acute respiratory distress syndrome (ARDS).

Recent findings—Because of the increased rate of severe perioperative respiratory complications in patients with OSA, the American Society of Anesthesiologists issued practice guidelines for perioperative management. When OSA is diagnosed preoperatively, the rate of postoperative pulmonary complications is low and not associated with OSA severity. However, OSA continues to be an important risk because a substantial proportion of patients in the contemporary surgical population have undiagnosed OSA. Strategies based on preoperative and immediate postoperative clinical signs and symptoms can help identify patients with a high likelihood of OSA, postoperative desaturations, and pulmonary complications. ARDS is another serious postoperative complication associated with high mortality rate and limited treatment options, and its prevention is critical. Practice changes have led to a dramatic reduction in ARDS incidence. A recently developed prediction model can help identify high-risk patients.

Summary—Evidence is emerging that early identification of modifiable risk factors and implementation of ‘protective’ management strategies may lead to reduction of severe postoperative pulmonary complications.

Keywords

acute respiratory distress syndrome; hypercapnic respiratory failure; hypoxic respiratory failure; obstructive sleep apnea; prediction scores

INTRODUCTION

Specific etiologic factors for respiratory failure after surgery can be broadly categorized into those portending risk of hypercapnic respiratory failure [e.g., obstructive sleep apnea (OSA)] and those portending risk of hypoxic respiratory failure [e.g., acute respiratory distress

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Conflicts of interest

There are no conflicts of interest.

syndrome (ARDS)]. Postoperative respiratory complications, including hypoventilation with hypercapnic respiratory arrest, are well documented in patients with OSA [1]. However, preoperative recognition of OSA or suspicion that the patient may have OSA allows for tailoring of perioperative management to minimize its impact on the postoperative course. Another serious complication is postoperative respiratory failure (PRF), especially when it arises from ARDS [2]. Of importance is the identification of patients at increased risk for this type of respiratory failure, because implementation of protective strategies, such as lung recruitment, ventilation with low tidal volumes, and restrictive fluid and transfusion practices, may reduce its occurrence [2,3■,4–6,7■■]. Our main objective is to describe approaches we use to identify patients at increased risk for postoperative OSA-associated complications and to describe factors that can facilitate the prediction of ARDS.

PREDICTING POSTOPERATIVE RESPIRATORY COMPLICATIONS IN PATIENTS WITH OBSTRUCTIVE SLEEP APNEA

Predictions of postoperative respiratory complications are based on patient characteristics, risks linked to comorbidities, especially OSA, as well as to the type of surgical procedure. Increased risk may be recognized with perioperative evaluation and may be mitigated with preventive measures.

Prevalence of obstructive sleep apnea in the surgical population

Because OSA is more prevalent in patients with advanced age and obesity – both characteristics frequently encountered in the contemporary surgical practice – perioperative complications related to OSA can be expected. Importantly, a large proportion of surgical patients have undiagnosed OSA, and an OSA-related complication may occur without anticipation. For example, OSA diagnosis was present in 15% of a cohort of bariatric surgical patients but, when assessed with polysomnography, was confirmed in 77% [8]. At the Mayo Clinic, where all bariatric patients undergo evaluation for sleep-disordered breathing, the incidence of OSA was 77.5% [9■].

Obstructive sleep apnea and postoperative complications

Anesthetic agents, sedatives, and opioids exaggerate airway obstruction and hypoventilation, which may lead to hypercapnic respiratory failure in patients with OSA. A large retrospective study found that surgical patients with OSA have a risk of postoperative tracheal intubation and mechanical ventilation that is several-fold higher than those without OSA [10]. In addition, investigators have shown that surgical patients with unrecognized OSA have higher rates of postoperative complications and ICU admissions and have longer hospital stays than those without OSA [11]. However, among bariatric surgical patients, when OSA was diagnosed preoperatively with polysomnography, management of OSA was optimized by treatment with noninvasive ventilation devices and when use of these devices continued during the postoperative period combined with vigilant monitoring, the overall complication rate was low and complications were not related to OSA severity [9■].

Perioperative diagnosis of obstructive sleep apnea

In 2006, the American Society of Anesthesiologists (ASA) published practice guidelines for the treatment of patients with OSA and recommended thorough preoperative evaluation and adjustment of anesthetic management to minimize postoperative respiratory depression [12]. The gold standard test for OSA diagnosis is overnight polysomnography [13]. Polysomnography yields the apneahypopnea index (AHI) score (an index of sleep apnea severity), and an AHI score greater than 5/h indicates the presence of OSA. The AHI score is the basis of the ASA rating of OSA severity as mild (AHI, 6–20/h), moderate (AHI, 21–40/h), and severe (AHI, ≥41/h) [12]. Of note, the AHI score of the American Academy of Sleep Medicine Task Force differs slightly from the one published by ASA [12]: no OSA (AHI, ≤4/h), mild OSA (AHI, 5–15/h), moderate OSA (AHI, 16–30/h), and severe OSA (AHI, ≥31/h) [14].

Polysomnography is expensive and of limited availability. Instead, overnight oximetry has been proposed as an OSA screening tool [15], with overnight oxygen desaturation index (ODI) scores greater than 10 desaturations per hour resulting in 93% sensitivity and 75% specificity to detect moderate-to-severe OSA [16]. However, some investigators show that overnight oximetry lacks diagnostic accuracy [17]. Its disadvantage is that, in patients for whom there is a high index of suspicion, a negative oximetry reading still needs confirmatory polysomnography.

Various screening tools of easily assessed clinical signs and symptoms have been used to identify patients at high risk for OSA. The Epworth Sleepiness Scale is a simple questionnaire that quantifies daytime sleepiness, a common symptom of OSA [18]. Correlation of the Epworth Sleepiness Scale scores with OSA continues to be controversial [18–20]. The Berlin Questionnaire queries the history of snoring, excessive daily sleepiness, and hypertension and takes into account demographic and anthropometric variables [21,22]. It has positive and negative predictive values of 77.9 and 44.9% for OSA and 31.5 and 92.8% for severe OSA, respectively [23].

The STOP (snoring, tiredness, observed apneas, high blood pressure) and the STOP-BANG (snoring, tiredness, observed apneas, high blood pressure, BMI >35 kg/m^2, age >50 years, neck circumference >40 cm, and male sex, with a score of ≥2 positives for STOP or ≥3 positives for STOP-BANG indicating high risk of OSA) assessment tools have been widely used as OSA screening tools with positive and negative predictive values of 81.0 and 60.8% for OSA and 31.0 and 100% for severe OSA, respectively [24,25]. The 2006 ASA practice guidelines propose a 14-item screening tool that assesses OSA predisposing physical characteristics, signs of airway obstruction during sleep, and somnolence [12]. This tool has positive and negative predictive values of 72.1 and 38.2% for OSA and 27.9 and 90.9% for severe OSA, respectively [24].

The Flemons criteria or sleep apnea clinical score (SACS) [26] shares similarities with STOP-BANG and the ASA screening tool in that it assesses hypertension, snoring, history of night-time airway obstruction, and neck circumference (Fig. 1) [26,27]. Patients with a high SACS have an 81% probability to have an AHI score greater than 10/h [26]. However, when Rowley *et al.* [28] evaluated four clinical screening questionnaires [26,29–31] and

compared them to polysomnography, they found that for an AHI at least 10/h, the sensitivities ranged from 76 to 96%, the specificities from 13 to 54%, and the positive predictive value from 69 to 77%. Thus, a negative result from these tools does not exclude the possibility of OSA.

New technologies are emerging to diagnose OSA during sleep [32] and wakefulness [33] and are based on the analysis of tracheal sounds. The rationale behind these methods lies in the anatomical and physiological differences of the pharyngeal structures among individuals with and without OSA [34]. Such differences produce alterations in the inspiratory and expiratory airflow characteristics of the upper airways that are amenable to analysis with the power spectral density of the sound signal. However, although preliminary studies have used tracheal sounds with considerable accuracy, these methods are still experimental and need further validation.

Postanesthesia recovery in patients with known and suspicious obstructive sleep apnea

The 2006 ASA guidelines recommend that when OSA is highly suspected, the patient should undergo preoperative preparation and modified perioperative management [12]. The guidelines admit that the medical literature is insufficient to make specific recommendations regarding monitoring or postoperative disposition (monitored vs. nonmonitored wards) [12]. Given the low specificities of simple clinical assessment tools [28], monitoring of all patients in whom OSA is suspected would add considerable strain to healthcare. Yet, patients with unrecognized OSA have a substantial risk of respiratory complications [11].

So far, we have demonstrated that questionnaires and overnight pulse oximetry cannot exclude the presence of OSA precisely. Therefore, the only definitive test for OSA is polysomnography, but it is expensive and has limited availability. A possible solution for patients with OSA or suspected OSA was proposed by Gali *et al.* [27,35]. They described a distinctive, two-phase evaluation process that combines preoperative assessment with nursing respiratory assessments during phase I recovery from anesthesia, to identify patients at risk. In these studies, adult surgical patients with an expected hospital stay more than 48 h and without a known diagnosis of OSA were screened with SACS [26]. During phase I recovery, registered nurses continuously monitored patients during three 30-min periods for four specific assessments: hypoventilation, apnea, desaturations, and ‘pain/sedation mismatch’ (defined as the presence of moderate-to-severe pain occurring in a moderately sedated patient; Tables 1 and 2) [35–37]. Any patient who had a respiratory-specific event during any two 30-min periods was considered to have a ‘recurrent respiratory event’. Patients were then categorized into four groups on the basis of SACS preoperatively and recurrent respiratory events during phase I recovery.

After discharge from phase I recovery, patients were monitored for episodes of ODI greater than 10 or other clinically meaningful respiratory complications (e.g., ICU admission for respiratory indication, noninvasive ventilatory support, pneumonia, respiratory arrest, respiratory therapy beyond clinical standards). In both studies, Gali *et al.* [27,35] found that patients with high SACS had more recurrent respiratory events in the recovery room. Episodes of ODI greater than 10 were more frequent among patients who had high SACS or had recurrent respiratory events. The likelihood of respiratory complications was 3.5-fold

greater in patients with high SACS or patients who had a 21-fold increased chance of recurrent events (Fig. 2) [35]. The highest risk of complications was in patients with both high SACS preoperatively and recurrent events in the recovery room [35].

On the basis of these findings, Seet and Chung [38] proposed a postoperative management pathway for patients with known OSA or in whom OSA was suspected (Fig. 3). The pathway takes into consideration respiratory events in the recovery room. Although this approach has not been validated in prospective studies, it incorporates the two-phase assessment concept of Gali *et al.* [27,35] and then suggests an algorithm for triage to appropriate postoperative care.

At Mayo Clinic, we have incorporated assessments of evaluation of respiratory-specific events in our discharge criteria from phase I anesthesia recovery (in addition to a modified Aldrete discharge criteria [36]). Any patient who has a respiratory-specific event must subsequently have two 30-min evaluation periods free of recurrent events before discharge from phase I recovery. In addition, any patient who has high SACS or recurrent respiratory events during phase I recovery but is identified as appropriate for discharge to a standard postsurgical ward is monitored remotely with continuous pulse oximetry for at least the first 48 postoperative hours.

PREDICTING POSTOPERATIVE ACUTE RESPIRATORY DISTRESS SYNDROME IN HIGH-RISK SURGICAL PATIENTS

A particularly concerning perioperative complication is PRF, which is defined as the failure to wean from mechanical ventilation within 48 h of a surgical procedure or an unplanned intubation/reintubation in the postoperative period [39■■]. Up to 5.4% of patients undergoing high-risk elective surgery may have PRF [40]. Numerous etiologic factors can lead to PRF, including hypercarbic respiratory failure from OSA, chronic obstructive lung disease exacerbation, and over-narcotization. A specific, common, and frequently lethal cause of PRF is ARDS, which accounts for approximately 35% of cases [40] and is characterized by injury to the alveolar-capillary barrier, with resultant alveolar flooding and hypoxemia [41]. Pathophysiologic mechanisms for ARDS include oxidative stress, lung deformation, inflammation, and intravascular coagulation [42]. Of note, the previously well-accepted American European Consensus Conference definitions for acute lung injury and ARDS [43] were revised recently by an ARDS Definition Task Force. In this revised Berlin Definition, acute lung injury is redefined as mild ARDS [44■■]. This modification was endorsed to help ensure that acute lung injury was not recognized inappropriately as a separate pathophysiologic entity.

The mortality rate of ARDS ranges from 25 to 45% [3■,40]. Recent estimates suggest that the incidence of postoperative ARDS is 3%, with the rate differing among different surgery types [45■]. Currently, supportive therapies continue to be the mainstay of ARDS management [46,47] and, therefore, ARDS prevention was identified as a key priority for the National Heart, Lung, and Blood Institute [48]. The importance of prevention was highlighted recently in a population-based study from Olmsted County, Minnesota [4]. This study demonstrated that over an 8-year period, the incidence of hospital-acquired ARDS

decreased more than 50% despite the fact that critical illness was increasing in severity and that presenting critically ill patients had a higher prevalence of predisposing conditions for ARDS. This finding suggests that changes in hospital practices can reduce the incidence of this dreaded complication. However, a critical barrier to progress in the prevention of ARDS has been the lack of effective predictive models that can identify high-risk populations. Without early risk stratification, any 'prevention strategy' will be delivered either too late or to the wrong population.

Identifying risks of postoperative respiratory failure

Substantial work has been conducted to identify risks associated with PRF. A landmark study evaluated male patients undergoing noncardiac operations at 44 US Veterans Affairs medical centers [49]. The investigators developed and validated a respiratory failure risk index to facilitate the identification of high-risk surgical cohorts. Specific risks included the nature of the operation (i.e., abdominal aortic aneurysm repair, neurosurgery, and thoracic, upper abdominal, peripheral vascular, neck, and emergency surgical procedures), specific laboratory abnormalities (i.e., albumin, <3.0 g/dl; blood urea nitrogen, >30 mg/dl), and clinical characteristics (i.e., older age, low functional status, and chronic obstructive pulmonary disease). The model's predictive accuracy was good, with an area under the curve (AUC) for receiver operating characteristics of 0.84.

In an effort to address the study's limitation (restriction to male patients in the Veterans Affairs medical system) [49], the same group conducted a follow-up investigation that included a relatively limited number of non-Veterans Affairs institutions (128 Veterans Affairs medical centers and 14 non-Veterans Affairs academic medical centers) [50], but again, more than 80% of the study patients were men. The investigators again identified procedure type and urgency, increased age, chronic obstructive pulmonary disease, renal insufficiency, and hypoalbuminemia to be the risk factors for PRF. The ASA physical status, preoperative congestive heart failure, ascites, or sepsis, or a combination, were also strong predictors. In addition, factors such as preoperative dyspnea, cerebrovascular disease, hepatic dysfunction, smoking, alcohol abuse, and various laboratory abnormalities (e.g., elevated white blood cell count, hypernatremia, thrombocytopenia, anemia) were associated with PRF. However, the effect estimates for this latter group of predictor variables were somewhat modest, and such associations have been identified less consistently. Regardless, this 28-variable predictive model performed well with an AUC of 0.86 in the validation cohort.

More recently, Gupta *et al.* [39■■] evaluated the American College of Surgeon's National Surgical Quality Improvement Program database to identify robust preoperative risk factors for PRF while developing a parsimonious and more generalizable risk prediction model. Among the 468 795 patients in the combined derivation and validation datasets, PRF developed in 2.8%. Notably, the 30-day mortality rate was higher in patients who had PRF than in those who did not (25.6 vs. 0.98%). Variables identified as predictors included the procedure type and urgency, ASA physical status, dependent functional status, and preoperative sepsis. Despite a reduced number of variables, performance of the predictive

algorithm remained good, with an AUC of 0.89 in the final model. Table 3 summarizes various risk factors for PRF.

Although numerous studies have evaluated specific risks for postoperative ARDS [45■], development of models that can accurately identify persons at high risk for ARDS has not been emphasized historically. Recently, Gajic *et al.* [3■] stimulated interest in addressing this knowledge gap in the Lung Injury Prediction Score (LIPS) study. Their study was a large, multicenter prospective cohort investigation that evaluated patients admitted to the hospital from the emergency department with at least one major risk factor for ARDS. Major predisposing conditions for ARDS and potential ARDS modifying factors were collected and evaluated for potential inclusion in a prediction model. In the final model, validated ARDS risk factors (i.e., shock, aspiration, sepsis, pneumonia, high-risk surgical procedure, and high-risk trauma) and statistically significant and biologically plausible ARDS risk modifiers (i.e., alcohol abuse, obesity, hypoalbuminemia, chemotherapy, hypoxemia, tachypnea, acidosis, and diabetes mellitus) were combined to derive the LIPS.

The LIPS algorithm performed well, with a validation dataset AUC of 0.80 [95% confidence interval (CI) 0.77–0.84]. When evaluating model performance through an optimal LIPS cutoff score of 4, the LIPS facilitated identification of a cohort of patients with an ARDS rate of 17%. Unfortunately, the target population evaluated in the LIPS study (medical and surgical patients presenting to the emergency department with major risk factors for ARDS) precludes its use in the majority of surgical patients (e.g., patients undergoing elective surgery who do not have such major risk factors for ARDS as sepsis, pneumonia, pancreatitis).

To address this limitation, we recently developed and validated a risk prediction score that specifically targets patients undergoing elective high-risk surgery [45■]. To derive the Surgical Lung Injury Prediction (SLIP) model, we collected preoperative variables that had been associated previously with development of postoperative ARDS and evaluated them for inclusion in a final predictive algorithm. Consistent with prior reports [3■,40], the nature of the surgical procedure was the most influential factor in ARDS development (Table 4) [45■]. Additional predictive factors were diabetes mellitus, chronic obstructive pulmonary disease, gastroesophageal reflux, and alcohol abuse. The model accurately discriminated patients who had ARDS from those who did not, with an AUC of 0.82 (95% CI 0.78–0.86). The SLIP model (Table 5) [45■] generates a SLIP score that can be used to define groups at low, moderate, and high risk for postoperative ARDS. In the evaluated study population, the frequency of postoperative ARDS was 0.54% in the low-risk, 2.62% in the moderate-risk, and 12.2% in the high-risk groups.

A group of particular concern for ARDS development are patients who have severe trauma, in whom the prevalence of ARDS ranges from 12 to 30%, with a mortality rate as high as 80% [51–53]. Watkins *et al.* [53] studied trauma patients at risk for ARDS and identified advanced age, severity of illness, type of injury (e.g., blunt trauma, pulmonary contusion, flail chest), and need for massive transfusion as ARDS risks. Although the predictive accuracy of this model was modest [AUC 0.71 (95% CI 0.68–0.74)], the model did outperform previous ones that had attempted to predict ARDS in similar populations

[54,55]. When evaluating the risk of trauma-related ARDS across studies, age, Injury Severity Score, massive transfusion, chest wall injuries, and pulmonary contusion appear to be relatively consistent predictors of ARDS [53–55].

CONCLUSION

Preoperative appreciation of factors associated with the development of severe postoperative respiratory complications allows us to tailor the perioperative care of high-risk patients that may lead to improved outcomes. We believe that patients with OSA and patients at high risk for development of postoperative ARDS represent specific groups that are amenable to preventive strategies.

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Papers of particular interest, published within the annual period of review, have been highlighted as:

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KEY POINTS

- Patients with OSA are at increased risk for postoperative respiratory complications; however, when OSA is recognized, complications can be mitigated.
- Formal diagnosis of OSA with polysomnography is cumbersome; thus, many surgical patients have unrecognized OSA.
- Various simple clinical tools with variable sensitivities and specificities are used to attempt to identify patients at increased risk for OSA.
- The ARDS is a common, life-threatening cause of postoperative hypoxemic respiratory failure, and because no effective treatment strategies exist, prevention is a major goal.
- The accurate identification of high-risk patients is a key element in ARDS prevention, and recently published prediction models can facilitate this aim.

Date: ___/___/___

Patient name: _____ Clinic No.: ___-___ ___ ___-___

Known OSA? ☐ No, complete remainder of this form
☐ Yes, refer to algorithm (unnecessary to complete form below)

Ask the patient the following questions and use the subsequent table to estimate risk of OSA.

1. Do you have high blood pressure or have you been told to take medication for high blood pressure? ☐ Yes ☐ No

2. "People who have shared (or are sharing) my bedroom tell me that I snore." Please pick the best response for the frequency of your snoring:

- ☐ I don't know
- ☐ Never
- ☐ Rarely (1 or 2 times per y)
- ☐ Occasionally (4-8 times per y)
- ☐ Sometimes (1 or 2 times per mo)
- ☐ Often (1 or 2 times per wk)
- ☐ Usually (3-5 times per week) [**equals 1 "Historical feature"**]
- ☐ Always (every night) [**equals 1 "Historical feature"**]

3. "I have been told by other people that I gasp, choke, or snort while I am sleeping." Please pick the best response for the frequency of any of these symptoms:

- ☐ I don't know
- ☐ Never
- ☐ Rarely (1 or 2 times per y)
- ☐ Occasionally (4-8 times per y)
- ☐ Sometimes (1 or 2 times per mo)
- ☐ Often (1 or 2 times per wk)
- ☐ Usually (3-5 times per week) [**equals 1 "Historical feature"**]
- ☐ Always (every night) [**equals 1 "Historical feature"**]

4. Neck measurment (we will measure you): ___ ___ cm

Total number of historical features: _____

Prediction of OSA (Circle the patient's score)

Neck circum-ference, cm	Sleep apnea clinical score					
	Not hypertensive Historical features*			**Hypertensive** Historical features*		
	None	One	Both	None	One	Both
<30	0	0	1	0	1	2
30/31	0	0	1	1	2	4
32/33	0	1	2	1	3	5
34/35	1	2	3	2	4	8
36/37	1	3	5	4	6	11
38/39	2	4	7	5	9	16
40/41	3	6	10	8	18	22
42/43	5	8	14	11	18	30
44/45	7	12	20	15	25	42
46/47	10	16	28	21	35	58
48/49	14	23	38	29	48	80
>49	19	32	53	40	66	110

[a]Historical features: 1. Habitual snoring 2. Partner reports of gasping, choking, or snorting

Probability of sleep apnea

☐ Low - Sleep apnea clinical score <15

■ High - Sleep apnea clinical score ≥15

Total sleep apnea clinical score:

_____

FIGURE 1.

Obstructive sleep apnea questionnaire. Adapted with permission from [27] and data from [26].

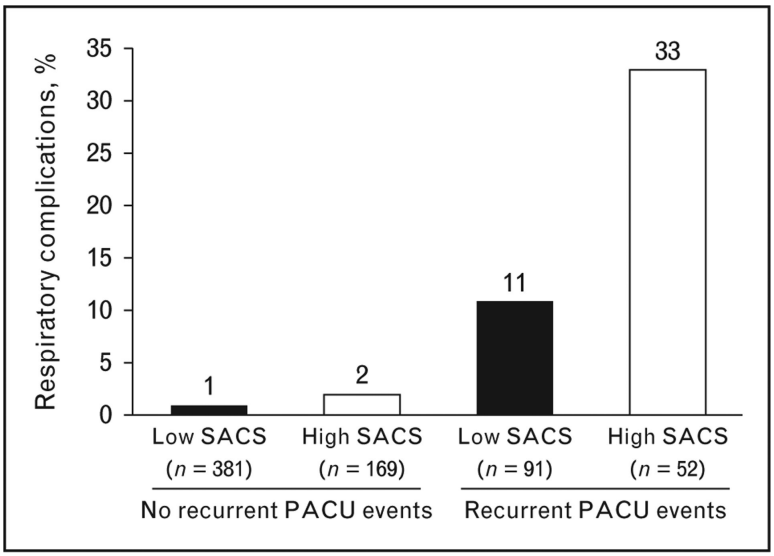

FIGURE 2.

Frequency of postoperative respiratory events. Events are shown in accordance with four patient groups defined by the combination of sleep apnea clinical score (SACS; low or high) and recurrent postanesthesia care unit (PACU) events (no or yes). A multiple logistic regression analysis included the SACS group and recurrent PACU events as explanatory variables and found that the likelihood of postoperative respiratory events was significantly associated with high SACS (odds ratio, 3.5; $P = 0.001$) and recurrent PACU events (odds ratio, 21.0; $P < 0.001$). Adapted with permission from [35].

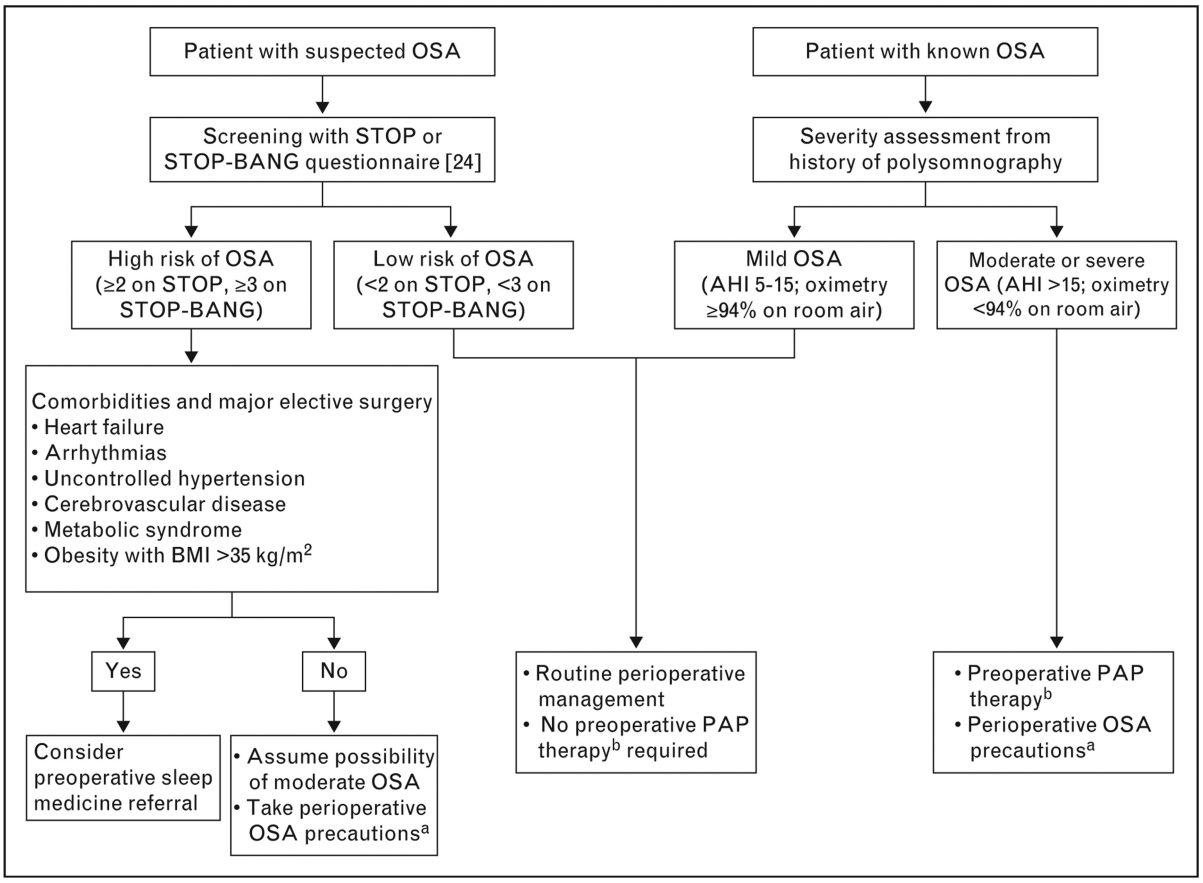

FIGURE 3.

Perioperative management in known or suspected obstructive sleep apnea. AHI, apnea-hypopnea index; OSA, obstructive sleep apnea; PAP, positive airway pressure; STOP, snoring, tiredness, observed apneas, high blood pressure; STOP-BANG, snoring, tiredness, observed apneas, high blood pressure, BMI more than 35 kg/m^2, age more than 50 years, neck circumference more than 40 cm, and male sex. [a] Perioperative OSA precautions include anticipation of possible difficult airway, use of short-acting anesthetic agents, opioid avoidance, verification of full neuromuscular block reversal, and extubation in a nonsupine position. [b] PAP therapy consists of continuous, bilevel, or autotitrating PAP. Adapted with permission from [38].

Table 1

Respiratory-specific assessment performed during phase I anesthesia recovery through postanesthesia care unit evaluation

Assessment	Evaluation period[a]		
Bradypnea: <8 respirations per min (3 episodes[b] needed for 'yes')	Initial 30 min after extubation or PACU admission (whichever occurs later)	Second 30 min after initial evaluation (60 min after extubation or PACU admission)	Third 30 min after second evaluation (90 min after extubation or PACU admission)
Apnea: ≥10s (only 1 episode needed for 'yes')			
Desaturations: pulse oxygen saturation <90% with nasal cannula (3 episodes needed for 'yes')			
Pain/sedation mismatch: RASS score –3 to –5 and Pain Scale Score[c] >5 (only 1 episode needed for 'yes')			

PACU, postanesthesia care unit; RASS, Richmond Agitation Sedation Scale.

Adapted with permission from [35].

[a]The first respiratory assessment is obtained during the first 30 min after extubation. If no respiratory-specific assessments occur, the patient can be dismissed when discharge criteria are met (i.e., modified Aldrete criteria) [36]. However, if an event occurs during the first 30 min, the patient must have two consecutive evaluation periods (30 min each) free of further events before being discharged from phase I recovery. Patients who have recurrent events, but eventually meet phase I discharge criteria for care in the standard postoperative ward, have continuous pulse oximetry for at least 48 h.

[b]Recurrent episodes are defined as any episode occurring at more than one evaluation period (not necessary to be same episode).

[c]Pain Scale Score is a standard, 11-point scale that ranges from 0 (no pain) to 10 (worst pain imaginable).

Table 2

Respiratory-specific assessment performed during phase I anesthesia recovery through Richmond Agitation Sedation Scale

Score	Term	Description
+4	Combative	Overtly combative or violent, immediate danger to staff
+3	Very agitated	Pulls on or removes tubes or catheters, aggressive toward staff
+2	Agitated	Frequent nonpurposeful movement or patient-ventilator dyssynchrony
+1	Restless	Anxious or apprehensive, but movements not aggressive or vigorous
0	Alert and calm	
–1	Drowsy	Not fully alert, sustained (>10s) awakening, eye contact to voice
–2	Light sedation	Briefly (<10s) awakens with eye contact to voice
–3	Moderate sedation	Any movement (but no eye contact) to voice
–4	Deep sedation	No response to voice, but any movement to physical stimulation
–5	Unarousable	No response to voice or physical stimulation

Adapted with permission from [37].

Table 3

Strength of evidence for associations among preoperative risk factors and development of postoperative respiratory failure

Strong evidence	Moderate evidence	Fair evidence
Advanced age	Intermediate-risk procedures[a]	Cerebrovascular disease
ASA physical status classification score >2	Congestive heart failure	Impaired sensorium
High-risk procedures[b]	Hypoalbuminemia	Hepatic dysfunction
Emergency procedures	Weight loss >10%	Preoperative dyspnea
Dependent functional status	Acute kidney injury/chronic kidney disease	Alcohol abuse
Chronic obstructive pulmonary disease	Ascites	Smoking
Sepsis		

ASA, American Society of Anesthesiologists.

[a]Intermediate-risk surgical procedures include peripheral vascular surgery, lower abdominal surgery, ear-nose-throat surgery, and endocrine surgery.

[b]High-risk surgical procedures include cardiac surgery, aortic aneurysm repair, thoracic surgery, upper abdominal surgery, and neurosurgery.

Table 4

Classification of cardiac, aortic vascular, and thoracic surgical procedures into low and high risk of acute respiratory distress syndrome

Low-risk surgical procedures		
Cardiac	**Aortic vascular**	**Thoracic**
Single valve repair	Primary abdominal aortic aneurysm repair	Video-assisted thoracoscopic surgery
ASD/VSD closure	Endovascular repair	Fundoplication surgery
Myectomy		Open lung biopsy
Sternal wound revision		Wedge lung resection
Pacemaker lead/device removal		Segmental lung resection

High-risk surgical procedures		
Cardiac	**Aortic vascular**	**Thoracic**
CABG	Descending thoracic aortic surgery	Multiple segmental lung resections
Valve replacement	Thoracoabdominal aortic surgery	Lobectomy
Multiple valve repair	Any revision aortic surgery	Multilobectomy
Pericardial resection		Pneumonectomy
Ascending aortic/aortic arch repair		Esophagectomy
Congenital heart repair		Lung decortication
Cardiac transplantation		
Cardiac reoperation		

ARDS, acute respiratory distress syndrome; ASD, atrial septal defect; CABG, coronary artery bypass grafting; VSD, ventricular septal defect. Adapted with permission from [45■].

Table 5

Surgical Lung Injury Prediction model scoring criteria

Criteria	SLIP points[a]
High-risk surgical procedure	
Cardiac	19
Vascular	32
Thoracic	16
Comorbidity	
Diabetes mellitus	6
COPD	10
GERD	7
Modifying condition	
Alcohol abuse	11

COPD, chronic obstructive pulmonary disease; GERD, gastroesophageal reflux disease; SLIP, Surgical Lung Injury Prediction.

[a]The SLIP score is the summation of the SLIP points. Score less than 10 corresponds with low risk; 10-26, moderate risk; and ≥27, high risk. Adapted with permission from [45■].