Sleep Study and Oximetry Parameters for Predicting Postoperative Complications in Patients With OSA

Colin Suen, MD, PhD; Clodagh M. Ryan, MD; Talha Mubashir, MD; Najib T. Ayas, MD; Lusine Abrahamyan, MD, PhD; Jean Wong, MD; Babak Mokhlesi, MD; and Frances Chung, MBBS

In the surgical setting, OSA is associated with an increased risk of postoperative complications. At present, risk stratification using OSA-associated parameters derived from polysomnography (PSG) or overnight oximetry to predict postoperative complications has not been established. The objective of this narrative review is to evaluate the literature to determine the association between parameters extracted from in-laboratory PSG, portable PSG, or overnight oximetry and postoperative adverse events. We obtained pertinent articles from Ovid MEDLINE, Ovid MEDLINE In-Process & Other Non-Indexed Citations, and Embase (2008 to December 2017). The search included studies with adult patients undergoing surgery who had OSA diagnosed with portable PSG, in-laboratory PSG, or overnight oximetry that reported on specific sleep parameters and at least one adverse outcome. The search was restricted to English-language articles. The search yielded 1,810 articles, of which 21 were included in the review. Preoperative apnea-hypopnea index (AHI) and measurements of nocturnal hypoxemia such as oxygen desaturation index (ODI), cumulative sleep time percentage with oxyhemoglobin saturation (SpO2) < 90% (CT90), minimum SpO2, mean SpO2, and longest apnea duration were associated with postoperative complications. OSA is associated with postoperative complications in the population undergoing surgery. Clinically and statistically significant associations between AHI and postoperative adverse events exists. Complications may be more likely to occur in the category of moderate to severe OSA (AHI ≥ 15). Other parameters from PSG or overnight oximetry such as ODI, CT90, mean and minimal SpO2, and longest apnea duration can be associated with postoperative complications and may provide additional value in risk stratification and minimization.

KEY WORDS: adverse events; obstructive sleep apnea; oximetry; perioperative; polysomnography

ABBREVIATIONS: AASM = American Academy of Sleep Medicine; AF = atrial fibrillation; AHI = apnea-hypopnea index; CT90 = cumulative time percentage with SpO2 < 90%; ODI = oxygen desaturation index; PSG = polysomnography; SpO2 = oxyhemoglobin saturation; UPPP = uvulopalatopharyngoplasty

AFFILIATIONS: From the Department of Anesthesiology (Drs Suen, Mubashir, Wong, and Chung), Toronto Western Hospital, University Health Network; the Department of Anesthesiology (Drs Suen, Wong, and Chung), the Department of Medicine (Dr Ryan), and the Toronto Health Economics and Technology Assessment Collaborative (Dr Abrahamyan), University of Toronto; and the Centre for Sleep Health and Research (Dr Ryan), Toronto General Hospital, Toronto, ON, Canada; the Sleep Disorders Program (Dr Ayas), University of British Columbia, Vancouver, BC, Canada; and the Sleep Disorders Center and the Section of Pulmonary and Critical Care (Dr Mokhlesi), Department of Medicine, University of Chicago, Chicago, IL.

This work was presented as a poster presentation at the International Anesthesia Research Society Meeting, April 30, 2018, Chicago, IL.

FUNDING/SUPPORT: This work was supported by University Health Network Foundation and Department of Anesthesiology, Toronto Western Hospital, University Health Network, University of Toronto, Toronto, ON, Canada. Dr Mokhlesi is supported by National Institutes of Health grant R01HL119161

CORRESPONDENCE TO: Frances Chung, MBBS, Department of Anesthesiology, University of Toronto, Toronto Western Hospital, University Health Network, 399 Bathurst St, Toronto, ON, M5T 2S8, Canada; e-mail: frances.chung@uhn.ca

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DOI: https://doi.org/10.1016/j.chest.2018.09.030
OSA is a common sleep-related breathing disorder characterized by recurring episodes of complete or partial upper airway obstruction during sleep. It is estimated that OSA affects up to 27% of women and 43% of men aged 50 to 70 years and 9% of women and 26% of men aged 30 to 49 years. In the surgical setting, OSA presents many challenges because it is associated with an increased risk of postoperative complications, including cardiac and pulmonary complications; oxygen desaturations; difficult intubation; and, in rare instances, death. The prevalence of OSA is estimated to be at least 25% among candidates for elective surgery and may be as high as 80% in high-risk populations such as patients undergoing bariatric surgery. In the patient with OSA, the intermittent upper airway obstruction leads to reductions in tidal volume and subsequent intermittent arterial hypoxemia and hypercapnia. The compensatory response involves a profound ventilatory response, activation of the sympathetic nervous system, and cortical arousals that disrupt normal sleep architecture causing daytime sleepiness. This response also results in peripheral vasoconstriction, depressed myocardial contractility, oxidative stress, inflammation, and endothelial dysfunction. Therefore, OSA is associated with cardiovascular sequelae such as coronary artery disease, left ventricular hypertrophy, hypertension, atrial fibrillation (AF), pulmonary hypertension, and cerebrovascular accidents. In the surgical setting, the administration of opioids, sedatives, and IV fluids may augment patient predisposition to sleep apnea by exacerbating upper airway collapse, depressing the arousal response, and intensifying rostral fluid shifts leading to upper airway edema and reduced patency. This difficulty is highlighted by the increase in both the severity of sleep apnea and arterial hypoxemia in those with known OSA and the emergence of de novo OSA in approximately 26% of patients undergoing surgery. Furthermore, these nocturnal respiratory events and episodic hypoxemia can be associated with significant postoperative sequelae, including cardiac ischemia and arrhythmias. The severity and duration of hypoxemia are also important because they have been correlated with the likelihood of myocardial ischemia. Gami et al observed that the incidence of sudden cardiac death was highest during normal hours of sleep (midnight to 6 AM) in patients with OSA. In contrast, patients without OSA experienced these events most frequently in the morning after 6 AM, which suggests a potential link between nocturnal sleep-disordered breathing and cardiovascular dysfunction. In the postoperative period, 80% of death or near-death events in patients with OSA are observed within the first 24 h after surgery, with the majority of these events occurring on the hospital ward, a vulnerable situation in which patients are not meticulously monitored. Therefore, it is of utmost importance to identify patients with OSA who are at risk of postoperative complications. The gold standard test for the diagnosis and determination of the severity of OSA is in-laboratory polysomnography (PSG). The 2017 clinical practice guideline for diagnostic testing for adult obstructive sleep apnea from the American Academy of Sleep Medicine (AASM) recommended use of alternative portable monitors for home diagnostic testing for OSA. In addition to the PSG technologies, high-resolution nocturnal oximetry has been suggested as a low-cost preoperative screening tool for OSA. For risk stratification in patients with OSA, it is unclear what, if any, specific parameters derived from the PSG or overnight oximetry are associated with postoperative complications. This knowledge is important for risk minimization and enhanced care of patients with known OSA who are undergoing surgery. The objective of this narrative review is to evaluate the literature to determine the association between parameters extracted from portable PSG, in-laboratory PSG, or overnight oximetry and postoperative adverse events.

Materials and Methods

Literature Search Strategy

For this review, we obtained pertinent articles from Ovid MEDLINE, Ovid MEDLINE In-Process & Other Non-Indexed Citations, and Embase by using a search method designed by an information specialist. To supplement our database searches, we also performed a citation search of references from primary or review articles. The comprehensive search included terms for “obstructive sleep apnea,” “sleep assessment,” and “perioperative and postoperative complications and adverse events” (e-Tables 1-3).

Study Selection Criteria

We included studies that (1) used in-laboratory PSG (type I), portable PSG, or overnight oximetry (types II-IV) to diagnose
OSA and/or assess patients with OSA; (2) reported on at least one postoperative adverse event; (3) reported on the following sleep parameters: apnea-hypopnea index (AHI), oxygen desaturation index (ODI), cumulative time with oxyhemoglobin saturation ($SpO_2$) < 90% (CT90), minimum $SpO_2$, mean $SpO_2$, or longest apnea duration; and (4) included an adult population aged ≥ 18 years. The search was restricted to English-language articles with a publication date limited to 2008 to December 2017. Studies were selected for inclusion first based on title and abstract review and relevance to the study question and then based on full-text review.

**Data Extraction**

We extracted information about study design, sample size, sleep study type and sleep monitor, reported sleep parameters, and postoperative complications. We summarized our findings by using narrative synthesis.

**Results**

The search yielded 1,810 articles, of which 21 fulfilled our inclusion criteria and were included in this review. Of the 21 articles, one was added following review of references from the included studies. Among studies reporting postoperative complications in patients with OSA, 19 studies reported on AHI, five on ODI, two on CT90, five on minimum $SpO_2$, one on mean $SpO_2$, and one on longest apnea duration (Table 1). The majority of studies measured short-term postoperative adverse outcomes (< 72 h). The most frequently observed events included oxygen desaturations and requirements for supplemental oxygen in the postanesthetic care unit. The more serious respiratory (pneumonia, respiratory failure, aspiration), cardiac (arrhythmia, cardiac arrest, acute coronary syndromes, heart failure, cardiogenic shock), and neurologic (cerebrovascular events, altered level of consciousness, delirium) complications were reported less frequently.

**Apnea-Hypopnea Index**

The AHI is defined as the total number of apneas and hypopneas per hour of sleep. The current AASM definition of an apnea is a reduction in airflow of at least 90% lasting at least 10 seconds, whereas a hypopnea is defined as a reduction in airflow of at least 30% with a concomitant decrease in $SpO_2$ by 3% to 4% from pre-event baseline and/or the event is associated with an arousal. The diagnosis and severity of OSA are determined using AHI thresholds: no OSA is an AHI < 5 events per hour, mild is an AHI ≥ 5 to < 15 events per hour, moderate is an AHI ≥ 15 to < 30 events per hour, and severe is an AHI ≥ 30 events per hour.

Of the 19 studies reporting postoperative complications and preoperative AHI, 12 showed significant associations between AHI and postoperative complications (Table 1). These studies evaluated diverse populations undergoing surgery. A number of studies were performed in patients undergoing upper airway surgery for OSA. In a nested case-control study, Kezirian et al studied 255 patients undergoing uvulopalatopharyngoplasty (UPPP) with PSG data and demonstrated that a higher AHI (52.8 vs 38.7 events per hour) was associated with serious complications. In contrast, in a retrospective 2-week follow-up study after UPPP surgery, Kandasamy et al did not demonstrate an association between the AHI and significant postoperative complications, although they found that an AHI ≥ 22 was associated with a twofold increased risk of requiring supplemental oxygen in the postanesthetic care unit. Those who had a higher AHI (37.4 vs 31.4 events per hour; $P = .05$) were more likely to require on-ward supplemental oxygen because of oxygen desaturations. In a retrospective study of 487 patients undergoing multilevel sleep apnea surgery by Pang et al, six patients with preoperative AHI > 60 experienced postoperative hypoxia after extubation. In contrast, a study in 95 patients with OSA undergoing upper airway surgery found that complication rates were not associated with the AHI.

The prevalence of OSA is estimated to be between 70% and 80% in those who are obese. Patients in this population are prone to a greater risk of postoperative cardiac and respiratory complications. Weingarten et al studied 797 patients undergoing bariatric surgery to determine whether there was an association between the AHI and postoperative complications. Although 33% of patients experienced postoperative complications, only age and BMI, but not the severity of OSA as defined by the AHI, were associated with an increased risk of postoperative adverse events. An important caveat was that most of these patients with OSA were receiving CPAP therapy at the time of surgery, so caution should be exercised in drawing conclusions and applying these results to patients with untreated OSA.

In a matched cohort analysis of PSG data and health administrative data in patients with OSA undergoing different types of surgery, Mutter et al reported that both diagnosed and undiagnosed severe OSA (AHI ≥ 30) were associated with more than a twofold increase in...
| Study/Year | No. of Patients | Study Design | Sleep Study Type | Monitoring Device | PAP Use | Parameter (Oxygen Desaturation Criteria) | Outcome | Findings (Complications vs No Complications) |
|------------|----------------|--------------|------------------|-------------------|---------|----------------------------------------|---------|--------------------------------------------|
| **Upper airway surgery** |                 |              |                  |                   |         |                                        |         |                                            |
| Asha’ari et al \cite{27} /2017 | 95             | Cohort-R     | Lab-PSG          | Crystal Sapphire (CleveMed) | Yes, if using preop | AHI | Postop Cx | NS                         |
| Kandasamy et al \cite{25} /2013 | 345            | Cohort-R     | Lab-PSG          | NR                | Not routine | AHI | O₂ in PACU | OR 2.2 for AHI $\geq$ 22 vs < 22 \cite{a} |
| Kezirian et al \cite{24} /2006 | 255            | Nested case-control | Lab-PSG          | NR                | NR | AHI | Postop Cx | Mean 53 vs 39 \cite{a} |
| Kim et al \cite{41} /2005 | 153            | Cohort-R     | Lab-PSG          | NR                | NR | AHI | Postop Cx | Mean 68 vs 49 \cite{a} |
| Pang et al \cite{26} /2012 | 487 (6)\cite{b} | Cohort-R     | Level III oximetry | WatchPAT 100 (Itamar Medical) | 50% preop CPAP trial for 1-2 wk | AHI | Postop SpO₂ desaturation | Mean AHI 67 vs 47 |
| **Cardiac surgery** |                 |              |                  |                   |         |                                        |         |                                            |
| Foldvary-Schaef er et al \cite{29} /2015 | 107            | Cohort-P     | Lab-PSG          | Crystal Monitor 20H | Preop PAP use excluded | AHI ($\geq$ 3%) | Postop Cx | NS |
| Mean 44% vs 53% in patients with AHI $\geq$ 15 vs < 15 \cite{a} NS |

(Continued)
| Study/Year | No. of Patients | Study Design | Sleep Study Type | Monitoring Device | PAP Use | Parameter (Oxygen Desaturation Criteria) | Outcome | Findings: (Complications vs No Complications) |
|------------|----------------|--------------|------------------|-------------------|---------|----------------------------------------|---------|---------------------------------------------|
| Kaw et al\textsuperscript{32}/2017 | 190 | Cohort-R | Lab-PSG | Nihon Kohden | 24% preop use | AHI ($\geq$ 3%) | OR 1.06 per 5-unit increase in AHI\textsuperscript{a} in unadjusted analysis (OR 1.04 in adjusted analysis; $P > .05$) | Effect modification with BMI > 32 kg/m\textsuperscript{2} |
| Kua et al\textsuperscript{34}/2016 | 150 | Cohort-P | Level III oximetry | WatchPAT 200 (Itamar Medical) | Preop PAP use excluded | AHI | AHI | OR 2.9 for AHI $\geq$ 15\textsuperscript{a} |
| Roggenbach et al\textsuperscript{37}/2014 | 92 | Cohort-P | Level III oximetry | MiniScreen 4 (Heinen and Löwenstein) | Postop CPAP if needed | AHI ($\geq$ 3%) | Delirium | OR 6.04 for AHI $\geq$ 19\textsuperscript{a} |
| Unosawa et al\textsuperscript{51}/2012 | 89 | Cohort-P | Level IV oximetry | SAS-2100 (Nihon Kohden) | No | AHI (postop) | AF | 19.2% vs 3.2% between AHI $\geq$ 15 vs < 15\textsuperscript{a} |
| Vascular surgery | | | | | | | | |
| Utriainen et al\textsuperscript{35}/2014 | 82 | Cohort-P | Lab-PSG | Embla / Somnologica (Natus) | No | AHI ($\geq$ 4%) | MACCE | HR 5.1 AHI $\geq$ 20 vs AHI < 20 for a median follow-up of 52 mo\textsuperscript{a} |
| Study/Year          | No. of Patients | Study Design | Sleep Study Type | Monitoring Device                  | PAP Use                          | Parameter (Oxygen Desaturation Criteria) | Outcome                                | Findings (Complications vs No Complications) |
|---------------------|-----------------|--------------|------------------|------------------------------------|----------------------------------|------------------------------------------|-----------------------------------------|---------------------------------------------|
| Bariatric surgery   |                 |              |                  |                                    |                                  |                                          |                                         |                                             |
| Turan et al^40^/2015| 218             | Cohort-R     | Lab-PSG          | NR                                 | 63% using preop CPAP             | CT90                                     | Opioid consumption                       | Decrease in median postop opioid consumption by 16% per 5% increase in CT90^a |
|                     |                 |              |                  |                                    |                                  | Minimum SpO2 AHI                        | Opioid consumption                       |                                             |
|                     |                 |              |                  |                                    |                                  |                                         | Opioid consumption                       |                                             |
|                     |                 |              |                  |                                    |                                  |                                         |                                         |                                             |
| Weingarten et al^30^/2011 | 797       | Cohort-R     | Lab-PSG          | NR                                 | 82% using preop PAP; postop PAP applied if preop use | AHI (≥ 2 or 4)                          | Postop Cx                               | NS among AHI categories (mild 5 ≤ AHI < 15, moderate 15 ≤ AHI < 30, severe AHI ≥ 30) |
| Other populations undergoing surgery |              |              |                  |                                    |                                  |                                          |                                         |                                             |
| Chung et al^21^/2014 | 573             | Cohort-P     | Level IV oximetry | PULSOX-300i (Konica Minolta Sensing) | None, undiagnosed OSA             | ODI 4                                   | Postop Cx                               | OR 2.2 for ODI > 29^a                      |
|                     |                 |              |                  |                                    |                                  |                                         |                                         |                                             |
|                     |                 |              |                  |                                    |                                  | CT90                                     | Postop Cx                               | OR 2.6 for CT90 > 7%^a                   |
|                     |                 |              |                  |                                    |                                  | Mean SpO2                                | Postop Cx                               | OR 2.8 for mean SpO2 < 93%^a             |
|                     |                 |              |                  |                                    |                                  |                                         |                                         |                                             |
| Devaraj et al^22^/2017 | 245     | Cohort-P     | Level III oximetry | Apnealink Plus (ResMed)             | None, undiagnosed OSA             | AHI (≥ 3%)                              | Postop Cx                               | OR 3.6 for AHI ≥ 5 (within 7 d postop)^a   |
|                     |                 |              |                  |                                    |                                  |                                         |                                         | OR 3.5 for AHI ≥ 5 (within 30 d postop)^b |
|                     |                 |              |                  |                                    |                                  |                                         |                                         | OR 6 for AHI ≥ 5                         |
|                     |                 |              |                  |                                    |                                  |                                         |                                         |                                             |
| Hwang et al^37^/2008 | 172             | Cohort-P     | Level IV oximetry | NR                                 | None, undiagnosed OSA             | ODI 4                                   | Postop Cx                               | OR 7.0 for ODI ≥ 5^a                     |
|                     |                 |              |                  |                                    |                                  |                                         |                                         | Mean 21% vs 10%^a                        |

(Continued)
| Study/Year     | No. of Patients | Study Design | Sleep Study Type | Monitoring Device                  | PAP Use      | Parameter (Oxygen Desaturation Criteria) | Outcome | Findings: (Complications vs No Complications) |
|----------------|----------------|--------------|------------------|------------------------------------|--------------|----------------------------------------|---------|------------------------------------------------|
| Kaw et al53/2016 | 519            | Cohort-R     | Lab-PSG          | NR                                 | 24% preop PAP use | AHI                                    | ICU LOS | AHI (per 15-unit increase) associated with increased ICU LOS in OHS cohort (β coefficient, 0.009) |
| Mador et al42/2013 | 284            | Cohort-R     | Lab-PSG          | NR                                 | Yes          | AHI                                    | Postop Cx | OR 2.0 for AHI ≥ 5 vs < 5<sup>a</sup>  
OR 2.3 for AHI 5 to < 30 vs AHI < 5<sup>a</sup> 
OR 1.92 for AHI 5 to <15 vs AHI < 5 (NS) 
OR 2.13 for AHI ≥ 30 vs AHI < 5 (NS) 
OR 2.05 for AHI ≥ 5 vs < 5<sup>a</sup>  
OR 2.18 for AHI 5 to < 15 vs AHI < 5<sup>a</sup> 
OR 2.01 for AHI 15 to < 30 vs AHI < 5 (NS) 
OR 2.07 AHI ≥ 30 vs AHI < 5 (NS) 
NS 
NS for arrhythmia |
| Mason et al38/2017 | 122            | Cohort-P     | Level IV oximetry | PULSOX-300i (Konica Minolta Sensing) | NR           | ODI 4                                  | ICU LOS | NS  |
| Mutter et al31/2014 | 20,442        | Cohort-R     | Lab-PSG          | NR                                 | NR           | AHI                                    | Respiratory Cx | OR 2.7 for AHI ≥ 30<sup>a</sup>  
OR 2.2 for cardiac Cx undiagnosed OSA vs OR 0.75 for diagnosed OSA<sup>a</sup> 
OR 2.7 for cardiac Cx in severe undiagnosed OSA + AHI ≥ 30 vs control group<sup>a</sup> |
|                | 19,405         | Cohort-R     | Lab-PSG          | NR                                 | NR           | AHI                                    | Cardiac Cx | NS  |
postoperative respiratory adverse events, whereas only undiagnosed severe OSA resulted in significant cardiac complications. In the population undergoing cardiac surgery, the relationship between the AHI and adverse outcomes was more evident. In this population, the occurrence of postoperative AF can be potentially fatal. In a study of 190 patients, Kaw et al\(^2\) reported 6\% increased odds of new onset AF per 5-unit increase in AHI. In a similar population of patients undergoing cardiac surgery, two studies demonstrated that AHI $\geq 19$ and AHI $\geq 15$ were associated with increased odds of postoperative delirium (OR, 6.0)$^{33}$ and postoperative acute kidney injury (OR, 2.9)$^{34}$ respectively. In a 1-year follow-up study in 84 patients undergoing surgical revascularization for peripheral artery disease, an AHI $\geq 20$ was predictive of major adverse cardiovascular and cerebrovascular events (hazard ratio, 5.1)$^{35}$.

Lastly, a study in 471 patients who had undergone various noncardiac or upper airway surgeries under general anesthetic, Kaw et al$^{36}$ reported that a diagnosis of OSA (as defined by an AHI $\geq 5$ events per hour) was associated with increased risk of postoperative hypoxemia, admission to the ICU, and longer hospital length of stay. No relationship between the AHI and postoperative complications was reported.

**Oxygen Desaturation Index**

Four studies were identified that used preoperative overnight oximetry to evaluate postoperative complications associated with an increased ODI (Table 1)$^{22}$. ODI is defined as the number of occurrences of an $\text{SpO}_2$ decrease by 3\% or 4\% (desaturation criteria vary from 3\% to 4\%) from baseline per hour. In a study of 172 patients undergoing general surgery, Hwang et al$^{37}$ observed a higher rate of postoperative complications in patients with an ODI $\geq 5$ vs that in those with an ODI $< 5$ events per hour (15.3\% vs 2.7\%; adjusted OR, 7.2). The rate of complications increased from 2.7\% among patients without nocturnal oxygen desaturation to 13.8\% in patients with an ODI 5 to 15 events per hour and to 17.5\% in patients with an ODI $\geq 15$ events per hour. In a large study comprising 573 patients undergoing general surgery, Chung et al$^{31}$ demonstrated that the optimal predictive cutoff for high risk of postoperative complications was an ODI $> 29$ events per hour, which was associated with an adjusted OR of 2.2. In 190 patients who had undergone cardiac surgery, Kaw et al$^{32}$ did not find an association between ODI and postcardiac surgery AF. With contrary findings, Mason et al$^{38}$ prospectively studied 122
patients undergoing cardiac surgery by using preoperative nocturnal oximetry to diagnose sleep apnea. Forty-seven percent of participants were categorized as having sleep apnea (ODI ≥ 5), and significant association was found between ODI ≥ 5 and all postoperative complications in the ICU (OR, 1.1); however, there were no significant differences in the incidence of postoperative arrhythmia.38

**Cumulative Time Percentage With Spo2 < 90%**

CT90 is defined as the cumulative time spent with Spo2 < 90% during sleep. Using overnight oximetry, Chung et al21 established that the optimal predictive cutoff for CT90 was 7%, which was associated with almost a twofold increased risk of postoperative complications. Hwang et al37 reported a significantly higher CT90 in the postoperative complications group vs that in the no complications group (21% vs 10%). Patients with OSA undergoing cardiac surgery who had a CT90 > 0 had significantly greater BMI, longer intraoperative endotracheal tube time, and greater prevalence of prolonged intubation.39 Finally, in patients who are obese and have sleep-disordered breathing, Turan et al40 showed that CT90 was inversely related to opioid consumption, which may suggest increased sensitivity to opioids.

**Minimum Spo2**

Minimum Spo2, also referred to as “nadir Spo2” or “lowest Spo2,” is defined as the lowest Spo2 value during a sleep study. In patients undergoing OSA surgery, Pang et al26 demonstrated that a minimum Spo2 < 80% was associated with postoperative complications (postextubation desaturations, tongue edema, negative pressure pulmonary edema, upper airway obstruction requiring reintubation). In patients undergoing UPPP surgery, Kim et al41 found that the minimum Spo2 measurements in patients with and those without complications were 71% vs 78%, respectively. Similarly, Asha’ari et al27 reported an OR of 1.03 for postoperative complications per 5% decrease in the minimum Spo2 for patients undergoing OSA surgery.

**Mean Nocturnal Spo2**

Only one study examined the mean Spo2 in relation to postoperative complications.21 In this study, there was a 2.7-fold increase in postoperative complications with use of preoperative nocturnal oximetry with an optimal predictive cutoff mean Spo2 < 93%.

**Apnea Duration**

In patients undergoing OSA surgery, Asha’ari et al27 demonstrated that the longest apnea duration was greater in patients with postoperative complications than in those without (51 vs 39 s). The odds of postoperative complications increased by 3% per 5-s increase in longest apnea duration.27

**Discussion**

This review has highlighted several parameters (such as AHI, ODI, CT90, minimum Spo2, mean Spo2, and longest apnea duration) extracted from in-laboratory or portable PSG or overnight oximetry that may be of importance to forewarn of postoperative complications. Of those evaluated, the AHI was the primary parameter derived from PSG used to determine the presence or absence of OSA and its severity.22 The current accepted AHI thresholds have been derived by consensus generated from observational and long-term studies.

In the current review, a diagnosis of AHI (AHI ≥ 5 per hour) alone is a predictor of postoperative complications,3 although data from multivariate logistic regression analysis27 and direct comparisons among AHI categories (mild, moderate, and severe)30,42 do not support a linear relationship between increasing AHI and the incidence of postoperative complications. However, an association has been shown between a higher AHI and increased postoperative events (Table 1).22 Among patients with diagnosed OSA, the mean AHI in the postoperative complications groups ranged from 37 to 68 events per hour. The majority of this evidence was based on patients undergoing upper airway corrective surgery for OSA. This population is at greater risk of postoperative upper airway edema and obstruction following surgery,14 and other respiratory, cardiac, and cerebrovascular complications were rare. Postoperative AF was more prevalent in patients undergoing cardiac surgery with an increasing AHI.32

Together, the heterogeneity in study design and patient characteristics and the often limited information available about the PSG technology and sleep scoring criteria among different studies make it difficult to establish an AHI cutoff for predicting postoperative complications that would be valid for all populations undergoing surgery. Furthermore, the AHI inherently assumes that apneas and hypopneas are equivalent, which is likely an oversimplification that does not recognize the pathophysiologic differences between complete vs partial airway obstruction.43 The AHI does
not indicate the magnitude and duration of oxygen desaturation, the negative intrathoracic pressure swings, or the arousal thresholds. Patients with high arousal thresholds may have an increased risk of respiratory events and an augmented sensitivity to opioids and sedatives.

The other OSA parameters assessed were measurements of arterial hypoxemia. These include CT90 and the mean and minimum SpO2 levels. A number of studies in populations with OSA suggest that the severity of nocturnal oxygen desaturation may be of similar or greater usefulness than the AHI for determination of cardiac dysfunction, endothelial impairment, hypertension, new onset and incident AF, and poor prognosis following myocardial infarction. In the medical literature, data exist that support measurements of nocturnal hypoxemia (ODI, CT90, minimum and mean SpO2) to provide supplementary clues about the severity of OSA and the risk of postoperative complications. In a large study (n = 543) that included oximetry data, the thresholds for predicting postoperative complications were an ODI > 29 per hour, CT90 > 7%, and mean SpO2 < 93%. Hwang et al found that patients with ODI ≥ 5 and CT90 > 21% experienced more postoperative complications. The rate of complications increased with the severity of OSA as determined by means of the ODI. In patients undergoing OSA surgery, several studies demonstrated that the lowest SpO2 was associated with postoperative adverse events.

Our review has highlighted several major limitations of the studies assessing postoperative complications in patients with OSA. Most of the studies were retrospective and relied on available documentation from medical records. Therefore, PSG data often were reported from chart review and/or reports from different sleep laboratories. The quality of the PSG studies was uncertain as was the scoring method. An AHI of 30 from one laboratory may not be equivalent to that from another. The North American AASM criteria allow for two differing scoring methods for hypopneas. The criteria for decrease in oxyhemoglobin desaturation can be > 3% or 4%, which can result in variability in the AHI. Details about the type of oximeters used to determine the oxygen parameters often were not provided. Moreover, these studies did not report details of opioid consumption, which could have a profound effect on the increasing severity of obstructive events and potentially influence postoperative complications. Another limitation, although not standard for PSG, is the lack of reporting on PSG-based end-tidal or transcutaneous carbon dioxide monitoring.

From our review of the literature, the most common postoperative complications were oxygen desaturation events, which are the hallmark manifestation of OSA. Thus, it may appear trivial that patients with preexisting abnormalities in nocturnal oximetry results would be more likely to experience postoperative arterial hypoxemia. Some patients, such as patients who are obese, may have a lower baseline SpO2 and may desaturate to a level requiring oxygen supplementation. Obesity reduces functional residual capacity and increases upper airway soft tissue and collapsibility, which play a role in OSA severity and may contribute to postoperative adverse events. Several of the included studies reported an association between elevated BMI and the incidence of postoperative complications (e-Table 4). AHI is associated with the incidence of new onset AF after cardiac surgery in patients with BMI > 32 kg/m². Furthermore, patients with an elevated AHI tended to have higher BMI. Another limitation of this study is that some of the included studies did not adjust for BMI in statistical modeling or report BMI. Patients with obesity hypoventilation syndrome (BMI > 30, OSA, daytime hypercapnia) are also at increased risk of postoperative complications, including respiratory failure, heart failure, and prolonged intubation. The included studies did not address the inclusion of patients with obesity hypoventilation studies, so obesity hypoventilation syndrome potentially is undiagnosed.

A major limitation of the current studies is that there is little to no data available on the long-term postoperative outcomes of patients undergoing surgery. We cannot yet conclude that these hypoxic events are inconsequential because there are reports of death or near death of patients with OSA undergoing surgery and the associated increasing medicolegal lawsuits. Nocturnal hypoxemia from OSA has been associated with endothelial dysfunction and major cardiovascular events after myocardial infarction. Patients with postoperative adverse events, including hypoxemia, had a longer hospital length of stay by 1 day than did patients without postoperative adverse events. Increased awareness of oximetry parameters should prompt further investigation into their association with short-term and long-term postoperative events because they are readily available from PSG and can be measured easily by use of wearable overnight oximetry methods.
Several other PSG-derived OSA parameters have been appraised for determining the severity of OSA. These included the duration of the apnea-hypopnea events and the magnitude and morphologic nature of oxygen desaturation. In addition, apnea severity and obstruction severity have been proposed as new parameters, and these are derived from the product of duration of individual events and the area under the curve of the associated SpO2 desaturation. In a 2013 nested case-control study, higher obstruction severity was related to mortality in patients with moderate to severe OSA. Although obstruction severity tends to increase with a higher AHI, there is much variability and overlap in this parameter within mild, moderate, and severe AHI categories. The heterogeneity in obstruction severity within similar AHI categories could reflect different arousal thresholds, with high arousal thresholds being associated with a diminished compensatory ventilatory response resulting in longer apneas with greater SpO2 desaturation. These parameters may offer more insight into the severity of OSA and deserve further study in populations undergoing surgery.

Other future areas of research also should consider the various phenotypes of OSA, which may indicate increased risk of postoperative complications. Evidence from a network-based cluster analysis suggests that populations with OSA are much more diverse than traditionally conceived because there are clusters of nonobese, thin-necked, normotensive individuals with OSA. Certain phenotypes of OSA, such as those with high arousal threshold or high loop gain, are underrecognized and may not be apparent immediately from the results of conventional PSG. Those with the phenotype with high arousal threshold have a low propensity to wake with obstructive events, which may predispose them to a greater magnitude of hypoxemia and hypercarbia within a respiratory event vs those in a patient with a similar AHI. This situation can be potentially disastrous in postoperative settings when opioids are used for pain relief. Those with the phenotype with high loop gain, characterized by an oversensitive ventilatory response to hypercapnia, may be predisposed to hyperventilation and hypocapnia leading to decreased respiratory drive and central sleep apnea. This cycle of overcompensation leads to unstable and perpetual cycles of hypoxia, which may predispose the patient to cardiac and pulmonary complications. In clinical practice, these parameters are not routinely used in PSGs and require further validation studies.

Conclusions

In summary, AHI and measurements of nocturnal hypoxemia (ODI, CT90, minimum and mean SpO2) are indexes of OSA that provide an imperfect assessment of the risk of postoperative complications. A significant association between the AHI and postoperative adverse events exists. Complications may be more likely to occur in the category of moderate to severe OSA (AHI ≥ 15). Other parameters from PSG or overnight oximetry such as ODI, CT90, mean and lowest SpO2, and longest apnea duration can be associated with postoperative complications and may provide additional value in risk stratification and minimization. These parameters can be incorporated into clinical decision tools for risk minimization.

Acknowledgments

Financial/nonfinancial disclosures: The authors have reported to CHEST the following: N. T. A. serves on the scientific advisory board of BresoTEC. B. M. has served as a consultant to Philips/Respironics and has received research support from Philips/Respironics. He has also received an honorarium from Zephyr Medical Technologies and has served on the advisory board of Itamar Medical. F. C. has received research support from Acacia Pharma; Medtronic grants to institution (University Health Network) outside of the submitted work; Ontario Ministry of Health and Long-Term Care; STOP-Bang, proprietary to the University Health Network; University Health Network Foundation; and UpToDate royalties. None declared (C. S., C. M. R., T. M., L. A., J. W.).

Role of sponsors: The sponsor had no role in the design of the study, the collection and analysis of the data, or the preparation of the manuscript.

Other contributions: The authors thank Marina Englesakis, HBA, MLIS (information specialist, Health Sciences Library, University Health Network) for her assistance with the literature search.

Additional information: The e-Tables can be found in the Supplemental Materials section of the online article.

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