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Identifying Risk of Postoperative Cardiorespiratory Complications in OSA

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BACKGROUND: Patients with OSA are at increased risk of postoperative cardiorespiratory complications and death. Attempts to stratify this risk have been inadequate, and predictors from large, well-characterized cohort studies are needed.

RESEARCH QUESTION: What is the relationship between OSA severity, defined by various polysomnography-derived metrics, and risk of postoperative cardiorespiratory complications or death, and which metrics best identify such risk?

STUDY DESIGN AND METHODS: In this cohort study, 6,770 consecutive patients who underwent diagnostic polysomnography for possible OSA and a procedure involving general anesthesia within a period of 2 years before and at least 5 years after polysomnography. Participants were identified by linking polysomnography and health databases. Relationships between OSA severity measures and the composite primary outcome of cardiorespiratory complications or death within 30 days of hospital discharge were investigated using univariable and multivariable analyses.

RESULTS: The primary outcome was observed in 5.3% (n = 361) of the cohort. Although univariable analysis showed strong dose-response relationships between this outcome and multiple OSA severity measures, multivariable analysis showed its independent predictors were: age older than 65 years (OR, 2.67 [95% CI, 2.03-3.52]; $P < .0001$), age 55.1 to 65 years (OR, 1.47 [95% CI, 1.09-1.98]; $P = .0111$), time between polysomnography and procedure of ≥ 5 years (OR, 1.32 [95% CI, 1.02-1.70]; $P = .0331$), BMI of ≥ 35 kg/m^2 (OR, 1.43 [95% CI, 1.13-1.82]; $P = .0032$), presence of known cardiorespiratory risk factor (OR, 1.63 [95% CI, 1.29-2.06]; $P < .0001$), > 4.7% of sleep time at an oxygen saturation measured by pulse oximetry of < 90% (T90; OR, 1.91 [95% CI, 1.51-2.42]; $P < .0001$), and cardiothoracic procedures (OR, 7.95 [95% CI, 5.71-11.08]; $P < .0001$). For noncardiothoracic procedures, age, BMI, presence of known cardiorespiratory risk factor, and percentage of sleep time at an oxygen saturation of < 90% remained the significant predictors, and a risk score based on their ORs was predictive of outcome (area under receiver operating characteristic curve, 0.7 [95% CI, 0.64-0.75]).

INTERPRETATION: These findings provide a basis for better identifying high-risk patients with OSA and determining appropriate postoperative care. CHEST 2024; 166(5):1197-1208

KEY WORDS: anesthesia; cardiopulmonary; cardiorespiratory; cardiovascular; complications; obstructive sleep apnea; OSA; postoperative; surgery

ABBREVIATIONS: AHI = apnea-hypopnea index; Spo_2 = oxygen saturation measured by pulse oximetry; T90 = percentage of sleep time at Spo_2 < 90%

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Take-home Points

Study Question: What is the relationship between OSA severity, defined by a range of polysomnography-derived metrics, and risk of postoperative cardiorespiratory complications or death, and which metrics best identify such risk?

Results: In a cohort study involving 6,770 patients who had undergone polysomnography for suspected OSA and a procedure involving general anesthesia within a period spanning 2 years before and at least 5 years after it, multivariable analysis demonstrated the independent risk factors were age, interval between polysomnography and procedure, BMI, presence of a known cardiovascular risk factor, percentage of sleep time spent at an arterial oxygen saturation of < 90%, and undergoing a cardiothoracic procedure.

Interpretation: For noncardiothoracic procedures age, BMI, presence of a known cardiovascular risk factor, and percentage of sleep time spent at an arterial oxygen saturation of < 90% remained the significant predictors, and a risk score based on their ORs was predictive of outcome, providing a basis for better identifying high-risk patients with OSA and determining appropriate postoperative care.

OSA is common, with an estimated global prevalence of almost 1 billion people.[1] Many studies show associations between OSA and increased risk of cardiovascular and respiratory problems, including coronary and cerebrovascular disease,[2,3] hypertension,[4] heart failure,[5] arrythmias,[6] worsening of COPD consequences,[7] and sudden death.[8] Furthermore, anatomic factors predisposing patients to OSA also predispose them to upper airway obstruction when sedated.[9] Sedation increases the risk of prolonged obstructive events because it depresses the usual arousal responses that protect people during sleep.[10]

Hence, the postoperative period can present particular risks for people with OSA, which seems to be an independent risk factor for postoperative cardiorespiratory complications.[11,12] However, uncertainty remains in identifying those at greatest risk among the many patients with OSA undergoing surgery. Limitations in previous studies have contributed to this. Many have used relatively unrefined tools to determine OSA presence, often inferring it from screening questionnaires that are nonspecific and provide no information about severity.[13,14] Others have used portable sleep monitoring to establish the diagnosis and its severity, which is less precise than polysomnography because of the limited number of parameters assessed, including lack of evaluation of sleep state.[12] Where a broader array of parameters has been examined, including from polysomnography, data often have been sourced from disparate centers.[15] The related potential for inhomogeneities in data collection or processing reduces the capacity to determine relative value of these various parameters in predicting postoperative outcomes. Of them, the most commonly used OSA severity metric has been the apnea-hypopnea index (AHI), but focus on this risks oversimplifying understanding of the condition,[16] potentially failing to identify important pathophysiologic factors contributing to postoperative risk. Finally, attempts to adjust for potential confounders in the relationship between OSA and risk of postoperative complications such as age, sex, and BMI have been inconsistent, leaving its independent effect uncertain.[14]

As a result, attempts to stratify risk according to OSA severity have been inadequate. Given the high proportion of patients undergoing surgery who have OSA, adequate risk stratification is an important challenge.[17] Without it, expensive high-acuity resources cannot be directed reliably to patients at greatest risk. This may result in waste through overzealous use where actual risk is low or, conversely, through inadequate provision where actual risk is high.

The objective of this study was to examine, in a large cohort of adults with suspected OSA who had undergone diagnostic polysomnography, the relationship between OSA severity defined by a variety of polysomnography-derived metrics and occurrence of postoperative cardiorespiratory complications and death. Our aim was to improve risk stratification by determining which metrics best identified postoperative risk.

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Study Design and Methods

A consecutive cohort of 13,412 adults investigated for suspected OSA at a major sleep clinic between August 1, 2002, and June 20, 2013, were studied. All had undergone diagnostic polysomnography (Compumedics), analyzed manually by qualified sleep technologists. Of these, patients having procedures requiring general anesthesia within a period spanning 2 years before and at least 5 years after polysomnography were selected, and occurrence of postoperative cardiorespiratory complications or death was documented. This was undertaken using state-wide hospital morbidity and mortality data from the Western Australian Data Linkage System, an acclaimed facility linking key health data sets for the entire Western Australian population.[18] These data are recorded routinely, are linked using probabilistic matching, and are audited continuously for quality control.[19]

The interval over which polysomnography results were considered was chosen because they were analyzed to a consistent benchmark for that period using American Academy of Sleep Medicine Chicago criteria[20] and because it allowed at least 5 years after the sleep study for a surgical admission to occur, with the first admission studied being on August 17, 2000, and final being on June 20, 2018.

The data were used to relate OSA severity, judged from various metrics, to occurrence of at least one adverse cardiorespiratory outcome within the same admission or any re-admission within 30 days of discharge after that admission. The primary adverse cardiorespiratory outcome (or primary outcome) was a composite of respiratory arrest, respiratory failure, adult respiratory distress syndrome, bacterial pneumonia, aspiration pneumonia, cardiac arrest and shock, acute coronary syndrome, atrial fibrillation and flutter not previously documented, pulmonary embolism, DVT, cerebrovascular accident, hypotension, and all-cause mortality (e-Table 1). These end points broadly are consistent with those in previous studies of adverse cardiovascular and respiratory outcomes after surgery.[21-23] The protocol was approved by the Human Research Ethics Committee of the Sir Charles Gairdner and Osborne Park Health Care Group (Identifier: HREC#2884).

Baseline Characteristics

Date of birth, sex, and BMI were collected at time of polysomnography. Presence of predisposing cardiorespiratory risk factors were determined from related International Classification of Diseases codes in the data registry between 2 and 12 years before admission for the procedure (e-Table 2).[19]

Polysomnography Parameters

Relevant parameters included AHI, arousal index, nadir oxygen saturation measured by pulse oximetry (Spo_2), percentage of sleep time at $Spo_2 < 90\%$ (T90), and apnea and hypopnea durations. Polysomnography data also were analyzed for average Spo_2 from lights out to sleep onset. Total duration of respiratory events was calculated by percentage of sleep time spent in hypopnea or apnea. Artefactual or spurious Spo_2 data were excluded.

Hospital Admission Data

Surgical procedure type was defined and categorized into cardiothoracic and noncardiothoracic groups.[24] Procedures involving cerebral, head and neck, or upper airway surgery and patients for whom the procedure was unknown were excluded because of potential to cause or exacerbate OSA. The hospital admission associated with general anesthesia for an eligible procedure nearest to the date of polysomnography was used as the index hospital admission for analysis. This and any readmission within 30 days of discharge after it were assessed for occurrence of adverse cardiorespiratory outcomes by International Classification of Diseases, 10th Revision, codes (e-Table 1) and deaths recorded. Where patients underwent multiple procedures over the study period, only the index admission and associated readmissions were considered.

Statistical Analysis

Standard descriptive statistics were used to summarize cohort characteristics, and the χ^2 statistic was used to assess univariable associations between occurrence of primary outcome and age, BMI, procedure type, and OSA severity, according to relevant polysomnography parameters. For each patient, data for the potential predictive variable were ordered into quartiles of increasing value to examine their relationship to outcome. Clinically applicable cut points were used for BMI. Patients with missing data for the parameter under consideration were excluded from this descriptive univariable analysis.

Significant relationships identified on univariable analysis then were entered into a multivariable logistic regression model. Multiple imputation was used to account for missing values in this analysis. Backward

elimination was used to determine statistically significant independent OSA-related predictors of adverse cardiorespiratory outcomes, after adjustment for age, interval between polysomnography and procedure, BMI, procedure type (cardiothoracic or noncardiothoracic), and presence of predisposing cardiorespiratory risk factors.

To develop a risk score for development of the primary outcome for noncardiothoracic procedures (described herein), the noncardiothoracic surgery data set was divided randomly into two sets of records with one containing approximately two-thirds of patients (the training data set) and the other containing one-third of patients (the test data set), each with the same proportion of patients with the end point present. A logistic regression model then was developed using the training data set to identify variables associated significantly with the end point (as described herein for the complete data set). Results were reported as ORs, their 95% CIs, and *P* values. Natural logarithms of ORs (ie, coefficients) were derived and used to weight each risk factor for calculation of a risk score for each patient in the test data set. This involved summing coefficients for each risk factor applicable to the patient concerned. The assembled risk scores of test data set patients then were tabulated in quartiles of increasing score to identify how well it stratified them from low-risk to high-risk of the end point developing. Score performance was tested further by receiver operating characteristic curve analysis for both test and training data sets. All analyses were undertaken using SAS version 9.4 software (SAS Institute Inc.), with a *P* value of $< .05$ taken to indicate a statistically significant association.

Results

Of the 13,412 patients who underwent polysomnography during the study period, 6,642 were excluded either because they had no hospital admission involving general anesthesia; because the index admission was for cerebral, head or neck, or upper airway surgery; because no procedure was identified; because BMI was missing; or because polysomnography data were incomplete (Fig 1).

The remaining 6,770 patients were included in final analysis. Ninety-two percent of patients (n = 6,237) had OSA (AHI $\geq$ 5 events/hr). Baseline characteristics and

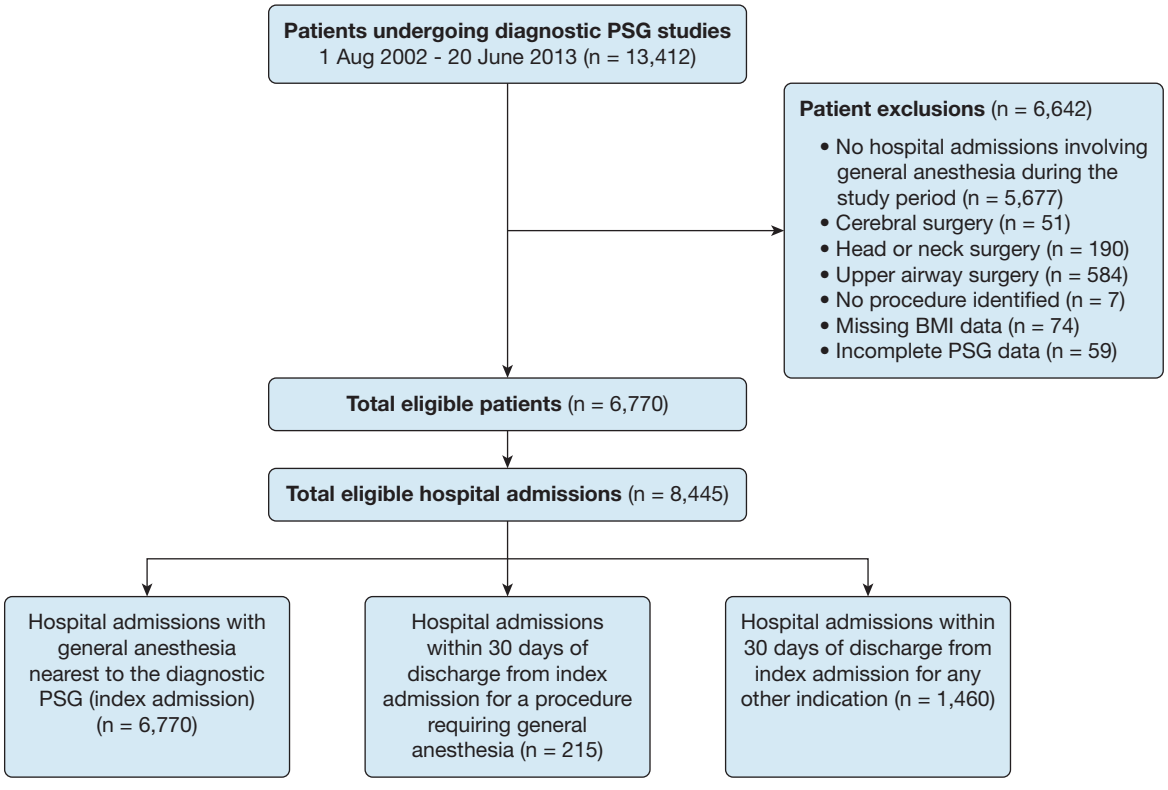

Figure 1 – *Participant flow diagram. PSG = polysomnography.*

polysomnography parameters are shown in e-Table 3, and types of operations undergone are shown in e-Table 4. Median age at time of procedure was 55.1 years (interquartile range, 44.8-64.8 years) and 57.7% (n = 3,905) were male. Median BMI at the time of polysomnography was 31.9 kg/m^2 (interquartile range, 28-37 kg/m^2). At least one risk factor for adverse cardiorespiratory events was detected in 40.2% of patients (n = 2,720).

Fifteen percent of patients underwent at least one readmission within 30 days of index admission, including 215 readmissions for further procedures requiring general anesthesia and 1,460 readmissions for nonsurgical indications. Hence, including 6,770 index admissions, 8,445 admissions were identified for potential analysis (Fig 1).

Hospital admissions for procedures under general anesthesia occurred a median of 1.5 years after polysomnography (interquartile range, 0.0-4.1 years), and 6,567 patients (97.0%) underwent noncardiothoracic procedures. In 29.5% of procedures, the patient was discharged on the day of the procedure.

Primary Outcome

One or more primary outcome end points were observed in 361 patients (5.3%) (Table 1): 287 patients (4.2%) experienced cardiac complications, 101 patients (1.5%) experienced respiratory complications, and 26 patients (0.4%) died. The proportion of patients with the outcome increased with increasing duration between polysomnography and procedure (e-Table 5)

TABLE 1] Incidence of Conditions Included in Composite Primary Outcome

Condition	No. of Patients With Condition (%)[a]
Respiratory conditions	
Respiratory arrest	4 (0.06)
Respiratory failure	49 (0.72)
Adult respiratory distress syndrome	2 (0.03)
Bacterial pneumonia	48 (0.71)
Aspiration pneumonia	14 (0.21)
Total respiratory complications[b]	**117 (1.73)**
Cardiac conditions	
Cardiac arrest and shock	25 (0.37)
Acute coronary syndrome	38 (0.56)
Atrial fibrillation and flutter (not preexisting)	30 (0.44)
Cerebrovascular accident	23 (0.34)
Hypotension	172 (2.54)
Pulmonary embolism	11 (0.16)
DVT	25 (0.37)
Total cardiac complications[c]	**324 (4.79)**
All-cause mortality	**26 (0.38)**
Patients experiencing ≤ 1 respiratory complications[b]	**101 (1.49)**
Patients experiencing ≤ 1 more cardiac complications[c]	**287 (4.24)**
Patients experiencing ≤ 1 more composite primary end points[d]	**361 (5.33)**

Boldface added to highlight totals.
[a]Percentages are based on the total No. of patients involved (n = 6,770).
[b]Some patients experienced > 1 respiratory complication.
[c]Some patients experienced > 1 cardiac complication.
[d]Some patients experienced both respiratory and cardiac complications.

Univariable Analysis

The primary outcome occurred more frequently with increasing age, time between polysomnography and procedure, BMI, presence of one or more cardiorespiratory risk factors, polysomnography indices of OSA severity (Table 2), and after cardiothoracic (vs noncardiothoracic) procedures (65/203 [31.0%] vs 296/6,567 [4.2%]; $\chi^2 = 295.26$; $P < .0001$). Regarding cardiorespiratory risk factors, the proportion of patients experiencing the primary outcome progressively increased with the number of these present (e-Table 6). Regarding type of procedure, although the proportion experiencing the primary outcome was disproportionately high with cardiothoracic surgery, no significant difference in occurrence was found between other major procedures (4.5%) and minor ones (4.8%; $\chi^2 = 0.26$; $P = .61$). Occurrence was similar for male and female patients (222/3,905 male patients (5.7%) vs 139/2,865 female patients (4.9%); $\chi^2 = 2.27$; $P = .13$).

The primary outcome was associated with all polysomnography indexes of OSA severity except arousal index. With each polysomnography index, risk increased progressively across quartiles of increasing severity (Table 2).

Multivariable Analysis

Of factors identified in univariable analysis, independent risk factors for the primary outcome were age, time between polysomnography and procedure, BMI, presence of at least one cardiorespiratory risk factor, T90, and a cardiothoracic procedure (Table 3). Regarding age, risk increased after 55 years of age, with a further increment in the quartile of > 65 years. For BMI,

TABLE 2] Univariable Relationships of Baseline Demographic and Polysomnography Characteristics to Occurrence of the Primary Outcome

Variable	Quartile of Severity or Magnitude				χ^2	*P* Value
	I	II	III	IV		
Age at time of the procedure						
Range, y	[16-45]	(45-55]	(55-65]	> 65	NA	NA
Primary outcome	41/1,723 (2.38)	61/1,648 (3.70)	93/1,747 (5.32)	166/1,652 (10.05)	111.23	< .0001
Interval between polysomnography and procedure						
Range, y	< 0	[0-2)	[2-5)	[5-13]	NA	NA
Primary outcome	48/1,178 (4.07)	123/2,178 (5.65)	96/1,952 (4.92)	94/1,462 (6.43)	8.27	.0408
BMI						
Range, kg/m^2	[14-25)	[25-30)	[30-35)	≥ 35	NA	NA
Primary outcome/total patients	39/748 (5.21)	73/1,841 (3.97)	92/1,880 (4.89)	157/2,301 (6.82)	17.68	< .0005
Presence of ≥ 1 cardiorespiratory risk factors	No		Yes		NA	NA
Primary outcome/total patients	147/4,050 (3.6)		214/2,720 (7.9)		57.89	< .0001
Apnea-hypopnea index						
Range, events/h	[0-12.5]	(12.5-25]	(25-48]	> 48	NA	NA
Primary outcome/total patients	69/1,705 (4.05)	80/1,724 (4.64)	104/1,693 (6.14)	108/1,648 (6.55)	14.29	.0025
Arousal index						
Range, events/h	[0-21]	(21-31]	(31-47]	> 47	NA	NA
Primary outcome/total patients	89/1,722 (5.17)	82/1,671 (4.91)	83/1,741 (4.77)	107/1,631 (6.56)	6.66	.0836
Average Spo_2 before sleep onset						
Range, %	> 97.0	(95.9-97.0]	(94.4-95.9]	[70-94.4]	NA	NA
Primary outcome/total patients	49/1,451 (3.38)	57/1,385 (4.12)	95/1,463 (6.49)	111/1,370 (8.10)	38.29	< .0001
Sleep time at Spo_2 < 90%, %						
Range, %	[0-0.05]	(0.05-0.57]	(0.57-4.7]	> 4.7	NA	NA
Primary outcome/total patients	48/1,703 (2.82)	65/1,677 (3.88)	88/1,696 (5.19)	160/1,691 (9.46)	85.52	< .0001
Nadir Spo_2						
Range, %	> 89	(85-89]	(79-85]	≤ 79	NA	NA
Primary outcome/total patients	55/1,785 (3.08)	64/1,733 (3.69)	94/1,575 (5.97)	141/1,619 (8.71)	65.61	< .0001
Difference between average Spo2 before sleep onset and nadir Spo_2						
Range, %	[0-8]	(8-11]	(11-17]	> 17	NA	NA
Primary outcome/total patients	56/1,582 (3.54)	47/1,158 (4.06)	78/1,429 (5.46)	124/1,437 (8.63)	43.81	< .0001

(Continued)

TABLE 2] *(Continued)*

Variable	Quartile of Severity or Magnitude				χ^2	*P* Value
	I	II	III	IV		
Longest apnea						
Range, s	[10-25]	(25-39]	(39-63]	> 63	NA	NA
Primary outcome/total patients	59/1,400 (4.21)	72/1,312 (5.49)	75/1,333 (5.63)	89/1,310 (6.79)	8.70	.0336
Longest hypopnea						
Range, s	[10-36]	(36-48]	(48-64]	> 64	NA	NA
Primary outcome/total patients	70/1,578 (4.44)	86/1,513 (5.68)	66/1,474 (4.48)	94/1,487 (6.32)	7.91	.0480
Sleep time in apnea, %						
Range, %	≤ 0.3	(0.3-1.0]	(1.0-3.6]	> 3.6	NA	NA
Primary outcome/total patients	65/1,653 (3.93)	76/1,523 (4.99)	82/1,648 (4.98)	119/1,599 (7.44)	21.32	< .0001
Sleep time in hypopnea, %						
Range, %	≤ 7	(7-14]	(14-25]	> 25	NA	NA
Primary outcome/total patients	65/1,591 (4.09)	76/1,685 (4.51)	87/1,574 (5.53)	114/1,573 (7.25)	18.73	.0003

Data are presented as No. of total No. (%) unless otherwise indicated. For ranges, a rounded bracket indicates that the end point of the range is not included, whereas a square bracket indicates that the end point of the range is included. NA = not applicable; Spo_2 = oxygen saturation measured by pulse oximetry.

increased risk was observed in the uppermost quartile (≧ 35 kg/m^2), as it was for T90 (> 4.7%). An alternate analytical approach where missing values were categorized separately, rather than imputed, yielded the same independent predictors with very similar ORs.

Risk Prediction Model

Given the substantial, well-understood risks associated with cardiothoracic procedures, a risk prediction score was developed for the 6,567 patients who underwent noncardiothoracic procedures only. Excluded were 201 patients who underwent cardiothoracic procedures as the index admission plus two patients who underwent a cardiothoracic procedure within the 30-day follow-up period after index admission. The training data set for this analysis included 4,378 patients, of whom 197 patients (4.5%) experienced the primary outcome. Apart from procedure type (excluded from this analysis a priori) and time between polysomnography and procedure (which was marginally significant in the overall group, but not significant here), the same variables identified for the entire cohort were significantly predictive of the primary outcome in this subset (Table 4).

Using the coefficients developed from the training data set, risk scores were calculated for the 2,189 test data set patients, of whom 99 patients (4.5%) experienced the primary outcome (Table 5, e-Table 7). They demonstrated a progressive increase in risk across quartiles of increasing severity ($\chi^2 = 48.5$; $P < .0001$). Areas under the receiver operating characteristic curve were 0.7 (95% CI, 0.64-0.75) and 0.69 (95% CI, 0.65-0.73) for the test and training data sets, respectively.

Discussion

In a large single-center cohort of patients who underwent polysomnography for suspected OSA, strong univariable dose-response relationships were observed between multiple measures of OSA severity and postoperative cardiorespiratory complications or death. These measures included AHI, average Spo_2 before sleep onset, T90, nadir Spo_2, apnea and hypopnea durations, and percentage of sleep time in apnea or hypopnea. However, after accounting for independent risk factors identified in the analysis not related to polysomnography (age, BMI, time between polysomnography and procedure, presence of at least one cardiorespiratory risk factor, and a cardiothoracic procedure), T90 was the only OSA severity measure

TABLE 3] Multivariable Analysis of Risk Factors for the Primary Outcome: All Patients

Variable	OR (95% CI)	*P* Value
Age at time of procedure, y		
16-55	1 (reference)	NA
55.1-65	1.47 (1.09-1.98)	.0111
> 65	2.67 (2.03-3.52)	< .0001
Interval between polysomnography and procedure, y		
< 5	1 (reference)	NA
≥ 5	1.32 (1.02-1.70)	.0331
BMI, kg/m^2		
< 35	1 (reference)	NA
≥ 35	1.43 (1.13-1.82)	.0032
Risk factor for cardiorespiratory events		
No	1 (reference)	NA
Yes	1.63 (1.29-2.06)	< .0001
Percentage of sleep time at Spo_2 < 90%		
≤ 4.7%	1 (reference)	NA
> 4.7%	1.91 (1.51-2.42)	< .0001
Cardiothoracic procedure		
No	1 (reference)	NA
Yes	7.95 (5.71-11.08)	< .0001

NA = not applicable; Spo_2 = oxygen saturation measured by pulse oximetry.

associated independently with the primary outcome. When cardiothoracic procedures were excluded from analysis, a risk prediction model for noncardiothoracic procedures based on age, BMI, presence of at least one cardiorespiratory risk factor, and T90 was associated strongly with adverse outcomes.

Given our emphasis on outcomes after general anesthesia, a wide range of surgical procedures was considered (e-Table 4). Clearly, considerable further diversity was present within these categories, but we wanted to capture outcomes across a multifaceted array of interventions.

TABLE 4] Development of a Risk Prediction Score for Occurrence of Postoperative Cardiorespiratory Complications in Patients With OSA After Noncardiothoracic Procedures: Multivariable Analysis of Risk Factors for the Primary Outcome in the Training Data Set (n = 4,378)

Variable	OR (95% CI)	*P* Value	Coefficient[a]
Age at time of procedure, y			
≤ 65	1 (reference)	NA	0
> 65	2.56 (1.89-3.47)	< .0001	0.94
BMI, kg/m^2			
< 35	1 (reference)	NA	0
≥ 35	1.57 (1.15-2.14)	.0046	0.45
Risk factor for cardiorespiratory events			
No	1 (reference)	NA	0
Yes	1.56 (1.15 – 2.10)	.0039	0.44
Percentage of sleep time at a Spo_2 < 90%			
≤ 4.7%	1 (reference)	NA	0
> 4.7%	1.84 (1.35 – 2.51)	.0001	0.61

NA = not applicable; Spo_2 = oxygen saturation measured by pulse oximetry.
[a]The coefficient is the natural logarithm of the corresponding OR, used to weight the risk factor for calculation of a risk score (see Methods).

TABLE 5] Development of a Risk Prediction Score for Occurrence of Postoperative Cardiorespiratory Complications in Patients With OSA After Noncardiothoracic Procedures: Relationship of Risk Prediction Score to Development of the Primary Outcome in the Test Subgroup (n = 2,189)

Score (range)	Proportion of Patients Demonstrating the Primary Outcome
0-0.5	24/1,159 (2.1)
0.5-1.0	20/394 (5.1)
1.0-1.5	33/454 (7.3)
> 1.5	22/182 (12.1)

Data are presented as No. of Total No. (%).

The internal validity of the findings was confirmed by the concordance observed between the training data set used to develop the risk prediction model and the independent test data set used to validate it. Although the population investigated was large and drawn from diverse sources across Western Australia, further studies are required to determine external validity.

The finding that OSA-related hypoxemia—characterized as T90—is a risk factor for adverse postoperative cardiorespiratory outcomes is consistent with previous studies demonstrating the predictive value of hypoxemia for such events.[15,25] It extends them by demonstrating that it is hypoxemia, perhaps reflecting hypoventilation, that is of pivotal importance in the relationship between OSA and postoperative outcomes, rather than OSA severity reflected in other measures, such as the widely used AHI.[11,12,26-30] The finding is also consistent with analyses of OSA-related risk of cardiorespiratory problems in nonsurgical settings, which also suggest that much OSA-associated risk relates to oxygenation and related oxidative stress.[31-40] That a parameter reflecting oxygenation is of most relevance to these postoperative outcomes is advantageous, because such data are obtained readily by overnight oximetry, which is relatively inexpensive, widely available, reliably used in unattended settings, and easily analyzed by automated means.[41]

The other independent risk factors are well recognized for their influence on postoperative cardiorespiratory outcomes. In the case of age and BMI, besides directly affecting postoperative risk, each is associated with OSA severity.[42] As such, accounting for them in determining OSA-related risk, as done here, is essential in establishing whether risk is related to OSA itself or to factors that contribute to OSA.

That cardiothoracic procedures present their own particular cardiorespiratory risks (Table 3) is well understood, and early postoperative care after them commonly is delivered in high-dependency settings.[43] However, an unresolved issue is in deciding which patients with OSA undergoing noncardiothoracic procedures merit high-acuity resources for postoperative care beyond the postanesthetic care unit. This is important given the well-documented risk of OSA-associated cardiorespiratory complications and the high number of patients with OSA undergoing surgery, often without a diagnosis.[12,37] The risk prediction tool for noncardiothoracic procedures (Table 4, e-Table 7) developed and tested here may help to make this determination.

Although screening tools, such as the widely used STOP-Bang questionnaire, are highly sensitive to presence of OSA, they are relatively nonspecific and do not directly assess severity.[13] Hence, where they raise the possibility of OSA before surgery, overnight measurements are needed to confirm its presence and severity.[17] The present study suggested that overnight oximetry alone is sufficient for this before surgery. The case for this was strong: for noncardiothoracic procedures, where T90 was more than 4.7%, the risk of the primary outcome almost doubled and only age older than 65 years was a stronger adverse prognostic factor.

The data were analyzed categorically to avoid assuming a linear trend in risk with increasing variable value. Categorization was carried out by separating variable values into quartiles, each containing a similar number of observations, except for BMI, where clinically applicable cutpoints were used for descriptive purposes. Often risk in the highest quartile disproportionately was greater than in the other quartiles, justifying the concern regarding any assumption of linearity.

It is important to note that these findings relate to a population that had been identified as being at risk of OSA, which was the prerequisite for them undergoing polysomnography. Although this could be regarded as a limitation, it is analogous to that of patients identified as being at risk of OSA by a preoperative screening tool, such as by questionnaire.[13] In both circumstances, subsequent study of breathing during sleep is needed if OSA is to be diagnosed and quantified.

It also should be noted that some of the cohort identified as having OSA already received treatment for it, the influence of which was not ascertained directly here. However, our comparison of outcomes from surgery

conducted before diagnostic polysomnography (and therefore before any treatment) with those conducted after (where a proportion of patients were prescribed treatment) showed no significant difference in proportions demonstrating cardiorespiratory complications (84 of 1,744 patients [4.8%] vs 277 of 5,026 patients [5.5%] respectively; $\chi^2 = 1.24$; $P = .27$). This is consistent with findings of a previous systematic review of effects of CPAP on postoperative outcomes in patients with OSA that showed no difference between those previously treated with CPAP and those not treated with it, questioning either treatment efficacy or long-term adherence.[44] Regarding longer-term effects, the increase we noted in proportion of patients experiencing the primary outcome with increasing time between polysomnography and procedure is consistent with age and time-related increases in severity of OSA.[45]

Another factor requiring consideration is our use of the now-superseded Chicago scoring rules. They were the standard at the time of polysomnography data collection, and use of them across all studies considered ensured scoring consistency. Their use is unlikely to be a serious limitation because previous work suggests their application yields very similar results as the use of contemporary scoring rules.[46,47] Regardless, the findings are readily transposed to these and to the use of simpler diagnostic methods, including oximetry alone.[48,49]

Another potential study limitation relates to big observational data sets.[50] Inevitably, missing values occur where data primarily are collected for nonresearch purposes. However, although the amount of missing data here was low, we performed imputational analysis to account for it. Further, although observational data risk residual confounding and bias, the data appear to be generalizable to real-world experiences of preoperative assessment where the clinical possibility of OSA is pursued.

Interpretation

This study demonstrated the importance of evaluating sleep-related hypoxemia in determining the risk of postoperative cardiorespiratory complications in patients with OSA. It suggested that parameters reflecting oxygenation are of greater relevance to the relationship between OSA and postoperative outcome than severity of OSA reflected in other metrics, such as AHI, the most widely used of these. It also showed that OSA-related postoperative risk is compounded by demographic and other factors, including age, BMI, presence of other known risk factors, and type of surgery. The study findings reinforced the importance of evaluating these other factors, some of which can exacerbate OSA itself, including age and obesity. This information is likely to improve evaluation of postoperative risk in patients with OSA.

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