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RESPIRATION AND THE AIRWAY

# Obstructive sleep apnoea and perioperative complications in bariatric patients

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## Key points

- Bariatric surgery is associated with increased number of postoperative complications.
- Case notes of 797 patients were reviewed to identify risk factors.
- Preoperative polysomnography had been performed to grade severity of obstructive sleep apnoea (OSA).
- Thirty-three per cent of patients had at least one complication; age, open procedure, and BMI, but not OSA severity, were associated with increased risk.

**Background.** The objective of this study was to determine the relationship between perioperative complications and the severity of obstructive sleep apnoea (OSA) in patients undergoing bariatric surgery who had undergone preoperative polysomnography (PSG).

**Methods.** The records of 797 patients, age >18 yr, who underwent bariatric operations (442 open and 355 laparoscopic procedures) at Mayo Clinic and were assessed before operation by PSG, were reviewed retrospectively. OSA was quantified using the apnoea–hypopnoea index (AHI) as none (≤4), mild (5–15), moderate (16–30), and severe (≥31). Pulmonary, surgical, and 'other' complications within the first 30 postoperative days were analysed according to OSA severity. Logistic regression was used to assess the multivariable association of OSA, age, sex, BMI, and surgical approach with postoperative complications.

**Results.** Most patients with OSA (93%) received perioperative positive airway pressure therapy, and all patients were closely monitored after operation with pulse oximetry on either regular nursing floors or in intensive or intermediate care units. At least one postoperative complication occurred in 259 patients (33%). In a multivariable model, the overall complication rate was increased with open procedures compared with laparoscopic. In addition, increased BMI and age were associated with increased likelihood of pulmonary and other complications. Complication rates were not associated with OSA severity.

**Conclusions.** In obese patients evaluated before operation by PSG before bariatric surgery and managed accordingly, the severity of OSA, as assessed by the AHI, was not associated with the rate of perioperative complications. These results cannot determine whether unrecognized and untreated OSA increases risk.

**Keywords:** anaesthesia, general; bariatric surgery; complications, perioperative; continuous positive pressure ventilation; non-invasive ventilation; obstructive sleep apnoea; polysomnography

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Morbidly obese patients may experience many serious co-morbidities ranging from cardiovascular disease to endocrine disorders. In particular, obstructive sleep apnoea (OSA) is often associated with morbid obesity with estimates for OSA prevalence in these patients exceeding 70%.[1] Even those morbidly obese patients who do not meet diagnostic criteria for OSA may experience upper airway resistance syndrome (UARS), a form of sleep-disordered breathing that also leads to sleep fragmentation and excessive daytime sleepiness.[2]

Several studies suggest that morbidly obese patients (BMI >35 kg m$^{-2}$) are at increased risk for perioperative complications compared with patients of normal weight,[3–7] and the markedly increased prevalence of OSA in the obese has been advocated as a mechanism. Despite assumptions that OSA itself is a significant independent risk factor for postoperative complications and despite the formulation of practice guidelines based on this assertion,[8] little evidence exists to support this association in any patient population.[9–12] Part of the difficulty in assessing OSA as a risk factor is that many

patients with OSA may be undiagnosed, and information from polysomnography (PSG), the 'gold standard' for the diagnosis of OSA,[13] is often not available.

It is not known how OSA affects perioperative risk in the morbidly obese, nor is it known if perioperative management of OSA by means such as non-invasive ventilation [continuous positive airway pressure (CPAP) or bi-level PAP] and postoperative monitoring may affect outcomes. If OSA is an independent risk factor for postoperative complications, we reasoned that the risk would increase with the severity of OSA, as defined by the PSG criterion of the apnoea–hypopnoea index (AHI). In contrast, if OSA is recognized and treated, it is possible that even if untreated OSA increased risk, then proper management could mitigate this risk.

The objective of this study was to determine the relationship between perioperative complications and the severity of OSA in patients undergoing bariatric surgery who had undergone preoperative diagnostic testing with PSG and received usual perioperative care for OSA patients. We tested the hypothesis that in these patients, the severity of OSA, as assessed by the AHI measured during PSG, would not be associated with the rate of perioperative complications.

## Methods

After obtaining approval from the Mayo Clinic Institutional Review Board (Rochester, MN, USA), we used the Mayo Clinic Bariatric Surgical database to identify and review medical records of all patients older than 18 yr of age who had first-time bariatric surgery between January 1, 2000 and December 31, 2006. Only data from patients who provided research authorization for the use of their medical records were included in the study [Minnesota Statute 144.335 Subd. 3a. (d)].

Preoperative evaluation of candidates for bariatric surgery is conducted by our Endocrinology Division typically 1–3 months before the planned operation. The possibility of OSA is considered in all bariatric surgical candidates. All patients with suspected OSA are referred for PSG. The patients with PSG-documented OSA are usually prescribed CPAP or bi-level PAP as the component of a comprehensive therapeutic approach to the management of OSA and OSA-related co-morbidities.[14 15] Given the multidisciplinary preparation for bariatric surgery, OSA patients have several weeks to months generally to try to establish consistent PAP use before presenting for bariatric surgery. To avoid differences in reporting PSG that may be present among different sleep laboratories, we included only patients who underwent testing at Mayo. Patients who were prescribed PAP before operation were instructed to bring their PAP device to the hospital. These devices are routinely applied in the recovery room immediately after tracheal extubation.

All PSGs were technologist-attended studies with data obtained via a computerized polygraph at our Center for Sleep Medicine. Electroencephalogram, electrooculogram, submental and anterior tibialis electromyogram, snoring by laryngeal microphone, oxyhaemoglobin saturation ($Sp_{O_2}$), and respiratory effort (thoracic, abdominal, and summated inductive plethysmography) were recorded. Airflow was analysed by an oronasal thermocouple until September 2001, then a nasal pressure transducer from October 2001 to August 2006, and then with both devices after August 2006. Until April 2002, hypopnoea was defined by a $\geq$30% decrease in airflow for at least 10 s despite respiratory effort and accompanied by at least a 2% decrease in $Sp_{O_2}$. Thereafter, the desaturation criterion was $\geq$4% to comply with the revised Center for Medicare and Medicaid Services policy. Obstructive apnoea was defined as a cessation of airflow for $\geq$10 s, despite ongoing respiratory effort (in contrast to central sleep apnoea where cessation of airflow is because of no respiratory effort). Arousals were scored according to contemporary standards during the period of data inclusion.[16] Respiratory effort-related arousals (RERAs) were defined as arousals after periods of at least 10 s of diminished airflow that did not meet criteria for hypopnoeas, or arousals after three or more crescendo snores. UARS was characterized by $\geq$10 RERAs per hour, a normal AHI ($<$5), and daytime symptoms attributable to the disordered breathing events.[2]

The electronic medical records were abstracted for patient characteristic information, co-morbid conditions, preoperative, intraoperative, and postoperative variables, and complications. Co-morbid conditions and complications were defined according to the modified definitions used for numerous outcome studies at Mayo Clinic over the last two decades[17] including: hypertension (medically treated), cardiovascular disease [coronary artery disease, history of heart failure including cor pulmonale, clinically relevant dysrhythmia (defined as atrial fibrillation/flutter, the presence of frequent ventricular ectopy on ECG, or implanted pacemaker)], pulmonary disease (asthma, chronic obstructive or restrictive pulmonary disease, acute lung injury defined as $Pa_{O_2}/Fi_{O_2}<300$ mm Hg, the presence of bilateral infiltrates, and pulmonary hypertension), diabetes mellitus (treatment with either insulin or oral agents), kidney disease (blood creatinine concentrations above age-adjusted norm), and obesity-related hepatobiliary disease (biopsy-proven non-alcoholic steatotic hepatitis diagnosed after operation, before operation, or both by otherwise unexplained increase in liver function tests).

Information reported from the preoperative PSG included the AHI (frequency of apnoea and hypopnoeas per hour of sleep) and nadir of $Sp_{O_2}$. OSA severity was categorized using the AHI (see the Statistical analyses section).[18] Information regarding the preoperative use of PAP was noted from surgical or other preoperative notes; however, information on preoperative compliance with therapy was not available.

In the post-anaesthesia care unit (PACU), CPAP or bi-level PAP units were applied in patients who were prescribed these devices before operation. Disposition after PACU discharge was at the discretion of the surgical service and anaesthesiologist, with options including (i) the intensive care unit with nursing supervision (1:1), (ii) an intermediary care unit where the patient is monitored continuously with close nursing supervision (1:2), and (iii) a regular nursing floor

with overnight pulse oximetry. All patients received supplemental oxygen at least for the first 24 postoperative hours. As part of standard Mayo Clinic policy, patients were encouraged to use their PAP devices postoperatively by physicians, nurses, and respiratory therapists.

Pulmonary complications were defined as being both clinically important and consistently available from the medical record, and included aspiration, suspected or definite pneumonia, requirement for CPAP or bi-level PAP in patients who did not use it before operation, the use of naloxone for respiratory depression, postoperative tracheal reintubation, mechanical ventilatory support after discharge from the recovery room, and respiratory arrest. Operative complications within the first 30 postoperative days (bleeding, wound dehiscence, anastomotic leak, wound infection, or the need for reoperation) were noted, and other complications [myocardial infarction, dysrhythmia, stroke, thromboembolic events, sepsis, liver failure (increase in liver transaminases), acute decline in renal function (from change in creatinine concentrations), hospital readmission, or death within 30 postoperative days].

All data were abstracted by one of the co-authors. To promote the uniformity of data abstraction, the first 10 records were reviewed by all abstractors, and any differences were reconciled in a discussion with the senior authors. After reconciling these differences, a standardized data abstraction process was adopted for the rest of the study.

### Statistical analyses

The severity of OSA was quantified using the AHI (which is reported in whole units) with categories defined as none ($\leq$4), mild (5–15), moderate (16–30), and severe ($\geq$31). This classification represents a slight modification (to avoid overlap between categories) of the American Academy of Sleep Medicine (AASM) criteria[18] and does not incorporate RERAs.

Patient and procedural characteristics were presented overall and according to the OSA category using mean (SD) for continuous variables and frequency percentages for categorical variables. These characteristics were compared across OSA categories (none *vs* mild *vs* moderate *vs* severe) using ANOVA for continuous variables and the $\chi^2$ test (or Fisher's exact test) for categorical variables. Postoperative complications were categorized as respiratory, surgical, and other (see above). For analysis purposes, a dichotomous variable was created for each category to identify patients who experienced one or more of the complications within the given category. In addition, an overall dichotomous variable was created to identify patients who experienced any postoperative complication. Because the frequency of complications differed for patients undergoing open *vs* laparoscopic technique, these data were summarized separately for each operative approach with complication rates compared across OSA groups using the $\chi^2$ test. Multiple logistic regression was used to assess the potential association of OSA with complications after adjusting for age, sex, BMI, and operative approach. The number of covariates to include in multivariable analysis was limited to 4 in order to avoid potential problems with overfitting. The covariates we included were determined before performing any multivariable modelling and were selected because they have been reported as risk factors for postoperative complications.[3–5 19–22] This approach of using subject knowledge expertise to a priori select a limited number of variables to be included in a multivariable model has been suggested as a preferred method for variable selection as opposed to step-wise selection or conducting univariate screening of variables for inclusion.[23] Separate models were fitted with OSA defined as a categorical variable (none, mild, moderate, severe) and also with AHI included as a continuous variable. To assess the consistency of findings, these models were also repeated separately for patients undergoing open *vs* laparoscopic technique. Similar analyses were performed using multiple linear regression to assess whether hospital duration of stay differed across OSA groups after adjusting for age, sex, BMI, and operative approach. In all cases, two-tailed *P*-values $<$0.05 were considered to be statistically significant. Analyses were performed using SAS statistical software (Version 9.1, SAS Institute, Inc., Cary, NC, USA).

## Results

### Preoperative characteristics

Between January 1, 2000 and December 31, 2006, 1495 patients older than 18 yr of age underwent bariatric surgery at Mayo Clinic in Rochester, MN, USA. Of these 1495 patients, 797 patients (442 undergoing open operations and 355 undergoing laparoscopic operations) were assessed by PSG at Mayo Center for Sleep Medicine and, therefore, met study inclusion criteria. Of these 797 patients, 179 (22.5%) did not meet criteria for OSA. The remainder met criteria for OSA with varying degrees of severity with 244 (30.6%) exhibiting severe OSA. As the classification of OSA increased (from none to severe), so also did the severity of oxyhaemoglobin desaturation during sleep (Table 1). Patient and procedural characteristics and disposition to different hospital units after bariatric surgery are summarized in Table 1. Within this cohort, 41.5% of the patients had a BMI$\geq$50 kg $m^{-2}$. Patients with OSA were older than those without OSA. Patients with more severe OSA were more likely to be male, have a greater BMI, undergo an open (*vs* laparoscopic) operation, and experienced a greater operative time. Most patients with OSA (93%) were prescribed preoperative CPAP or bi-level PAP; 78 (43.6%) of the 179 patients who did not meet diagnostic criteria for OSA were also prescribed CPAP or bi-level PAP before operation. The majority of these patients (51 of 78, 65.4%) were diagnosed with UARS. Indications for non-invasive ventilation in the remaining patients were not always clear but included disruptive snoring not otherwise meeting criteria for UARS. The prevalence of most obesity-related co-morbid conditions increased with OSA category (Table 1). In the PACU, five (1%) patients required naloxone (one without, one with moderate, and three with severe OSA). Most patients (86%) were transferred

**Table 1** Patient and procedural characteristics. OSA categories are defined by AHI as none (≤4), mild (5–15), moderate (16–30), and severe (≥31). Data are presented using mean (SD) for continuous variables and *n* (%) for categorical variables. Characteristics are compared across OSA groups (none *vs* mild *vs* moderate *vs* severe) using ANOVA for continuous variables and $\chi^2$ or Fisher's exact test for categorical variables. CPAP, continuous positive airway pressure; $Sp_{O_2}$, arterial oxygen saturation by pulse oximetry, # $h^{-1}$, number per hour. †Duration of anesthesia was also found to differ across OSA groups in analyses performed separately for open and laparoscopic procedures ($P<0.01$ for both). ‡Data were obtained from PSG. ¶Of those with respiratory disease, 18 had pulmonary hypertension (three none, six mild, two moderate, and seven severe)

| | Total (*n*=797) | Obstructive sleep apnoea category | | | | *P*-value |
|---|---|---|---|---|---|---|
| | | 1=none (*n*=179) | 2=mild (*n*=247) | 3=moderate (*n*=127) | 4=severe (*n*=244) | |
| Age (yr) | 46.6 (10.8) | 43.3 (9.9) | 47.5 (10.6) | 47.1 (11.4) | 47.9 (11.0) | <0.001 |
| Sex [*n* (%)] | | | | | | |
| Male | 206 (25.8) | 10 (5.6) | 39 (15.8) | 41 (32.3) | 116 (47.5) | <0.001 |
| Female | 591 (74.2) | 169 (94.4) | 208 (84.2) | 86 (67.7) | 128 (52.5) | |
| BMI (kg $m^{-2}$) | 49.5 (9.4) | 46.3 (7.7) | 48.1 (8.6) | 50.7 (10.2) | 52.7 (9.7) | <0.001 |
| Superobese (BMI≥50) [*n* (%)] | 331 (41.5) | 46 (25.7) | 86 (34.8) | 57 (44.9) | 142 (58.2) | <0.001 |
| Preoperative use of CPAP [*n* (%)] | | | | | | <0.001 |
| No | 143 (17.9) | 101 (56.4) | 33 (13.4) | 5 (3.9) | 4 (1.6) | |
| Yes | 654 (82.1) | 78 (43.6) | 214 (86.6) | 122 (96.1) | 240 (98.4) | |
| Apnoea–hypopnoea index (# $h^{-1}$)‡ | 29.1 (36.0) | 1.8 (1.3) | 9.1 (3.1) | 21.9 (4.2) | 73.2 (35.8) | <0.001 |
| Minimum $Sp_{O_2}$ (%)‡ | 80.4 (11.2) | 88.1 (4.2) | 82.6 (6.8) | 78.7 (11.0) | 73.3 (13.7) | <0.001 |
| Co-morbid diseases [*n* (%)] | | | | | | |
| Diabetes | 271 (34.0) | 46 (25.7) | 78 (31.6) | 50 (39.4) | 97 (39.8) | 0.010 |
| Hypertension | 439 (55.1) | 84 (46.9) | 133 (53.8) | 76 (59.8) | 146 (59.8) | 0.039 |
| Cardiovascular disease | 126 (15.8) | 18 (10.1) | 37 (15.0) | 31 (24.4) | 40 (16.4) | 0.008 |
| Respiratory disease¶ | 221 (27.7) | 53 (29.6) | 68 (27.5) | 36 (28.3) | 64 (26.2) | 0.892 |
| Hepatobiliary disease | 202 (25.3) | 41 (22.9) | 65 (26.3) | 26 (20.5) | 70 (28.7) | 0.293 |
| Renal insufficiency | 72 (9.0) | 8 (4.5) | 16 (6.5) | 9 (7.1) | 39 (16.0) | <0.001 |
| Surgical approach [*n* (%)] | | | | | | |
| Open | 442 (55.5) | 84 (46.9) | 117 (47.4) | 78 (61.4) | 163 (66.8) | <0.001 |
| Laparoscopic | 355 (44.5) | 95 (53.1) | 130 (52.6) | 49 (38.6) | 81 (33.2) | |
| Duration of anesthesia (min)† | 289 (83) | 265 (73) | 278 (80) | 291 (83) | 317 (85) | <0.001 |
| Postoperative monitoring level [*n* (%)] | | | | | | |
| Intensive care unit | 130 (16.3) | 27 (15.1) | 32 (13.0) | 25 (19.7) | 46 (18.9) | <0.001 |
| Intermediate care unit | 556 (69.8) | 103 (57.5) | 174 (70.4) | 95 (74.8) | 184 (75.4) | |
| Regular nursing floor | 111 (13.9) | 49 (27.4) | 41 (16.6) | 7 (5.5) | 14 (5.7) | |

from the PACU to monitored surgical units during first postoperative night (intensive care unit or intermediate care units), with those with more severe OSA receiving more intensive postoperative monitoring (Table 1). Those patients transferred to the floor were monitored with pulse oximetry.

At least one postoperative complication occurred in 259 patients (32.5%) with the most common complication being readmission within 30 days after operation (112 patients, 14.0%). Some patients had multiple indications for readmission; the most common indications included wound infection (*n*=35), pain (*n*=22), inability to eat (*n*=20), wound dehiscence (*n*=13), bleeding (*n*=10), and cardiovascular complications (*n*=6). Surgical wound infections occurred in 66 (8.3%) patients. Three patients died within the first 30 days after operation (0.4%, one patient suffering a pulmonary embolism and two succumbing to sepsis) and 34 patients (4.3%) required reoperation within 30 days. The proportion of patients experiencing at least one complication was greater among those who underwent open operations compared with those undergoing laparoscopic procedures (39.1% *vs* 24.2%, $P<0.001$).

The complication rates are presented according to the OSA category separately for those undergoing open (Table 2) and laparoscopic (Table 3) procedures. The frequency of complications was not significantly different according to the OSA category in univariate analyses performed separately for open and laparoscopic procedures. Similar findings were obtained when AHI was treated as a continuous variable and compared between those who experienced complications *vs* not. Among those undergoing open procedures, AHI did not differ significantly between those who experienced any complication *vs* not [median (inter-quartile range) AHI was 17 (7, 46) *vs* 19 (6, 51) in those who experienced complications *vs* not; rank-sum test, $P=0.642$] and also did not differ significantly between those who experienced pulmonary complications *vs* not

**Table 2** Postoperative complications and duration of hospital stay among patients undergoing open procedures. CXR, chest radiogram; CPAP, continuous positive airway pressure; ARDS, adult respiratory distress syndrome; PACU, postoperative anesthesia care unit. *OSA categories are defined by AHI as none (≤4), mild (5–15), moderate (16–30), and severe (≥31). †Data are compared across OSA groups using the $\chi^2$ test for complications and ANOVA for length of stay. When the frequency of complications was compared across OSA treated as a dichotomous variable (none vs mild, moderate, or severe), no significant differences were found. Because some patients experienced multiple complications, the overall rate for a given category is less than the sum of the individual complications. ‡Initiation of CPAP in patients who did not have it before operation. ¶Although hospital readmission is included in the 'other complication' category, a pulmonary complication (e.g. pneumonia) or surgical complication (e.g. wound infection) may have been the reason for readmission

| | Total (*n*=442) | Obstructive sleep apnoea category* | | | | *P*-value† |
|---|---|---|---|---|---|---|
| | | 1=none (*n*=84) | 2=mild (*n*=117) | 3=moderate (*n*=78) | 4=severe (*n*=163) | |
| At least one complication [*n* (%)] | 173 (39.1) | 28 (33.3) | 52 (44.4) | 31 (39.7) | 62 (38.0) | 0.446 |
| Pulmonary complications [*n* (%)] | 45 (10.2) | 5 (6.0) | 11 (9.4) | 12 (15.4) | 17 (10.4) | 0.257 |
| Respiratory arrest | 3 (0.7) | 0 (0.0) | 0 (0.0) | 1 (1.3) | 2 (1.2) | |
| Aspiration (CXR+written note) | 1 (0.2) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 1 (0.6) | |
| Pneumonia | 8 (1.8) | 2 (2.4) | 3 (2.6) | 1 (1.3) | 2 (1.2) | |
| Acute lung injury | 1 (0.2) | 0 (0.0) | 0 (0.0) | 1 (1.3) | 0 (0.0) | |
| Ventilatory support beyond PACU | 27 (6.1) | 0 (0.0) | 6 (5.1) | 8 (10.3) | 13 (8.0) | |
| Initiation of CPAP‡ | 3 (0.7) | 2 (2.4) | 1 (0.9) | 0 (0.0) | 0 (0.0) | |
| Use of naloxone | 6 (1.4) | 1 (1.2) | 1 (0.9) | 2 (2.6) | 2 (1.2) | |
| Need for tracheal reintubation | 12 (2.7) | 0 (0.0) | 4 (3.4) | 5 (6.4) | 3 (1.8) | |
| Surgical complications [*n* (%)] | 89 (20.1) | 11 (13.1) | 28 (23.9) | 17 (21.8) | 33 (20.2) | 0.287 |
| Bleeding | 22 (5.0) | 2 (2.4) | 12 (10.3) | 4 (5.1) | 4 (2.5) | |
| Wound dehiscence | 32 (7.2) | 4 (4.8) | 5 (4.3) | 7 (9.0) | 16 (9.8) | |
| Anastomotic leak | 8 (1.8) | 0 (0.0) | 5 (4.3) | 1 (1.3) | 2 (1.2) | |
| Wound infection | 52 (11.8) | 9 (10.7) | 10 (8.5) | 9 (11.5) | 24(14.7) | |
| Reoperation | 17 (3.8) | 0 (0.0) | 5 (4.3) | 5 (6.4) | 7 (4.3) | |
| Other complications [*n* (%)] | 102 (23.1) | 19 (22.2) | 32 (27.4) | 17 (21.8) | 34 (20.9) | 0.629 |
| Death | 2 (0.5) | 0 (0.0) | 1 (0.9) | 0 (0.0) | 1 (0.6) | |
| Myocardial infarction | 5 (1.1) | 2 (2.4) | 1 (0.9) | 0 (0.0) | 2 (1.2) | |
| Dysrhythmia | 7 (1.6) | 0 (0.0) | 2 (1.7) | 1 (1.3) | 4 (2.5) | |
| Stroke | 1 (0.2) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 1 (0.6) | |
| Thromboembolic | 2 (0.5) | 0 (0.0) | 2 (1.7) | 0 (0.0) | 0 (0.0) | |
| Severe sepsis | 4 (0.9) | 0 (0.0) | 1 (0.9) | 2 (2.6) | 1 (0.6) | |
| Liver failure | 1 (0.2) | 0 (0.0) | 1 (0.9) | 0 (0.0) | 0 (0.0) | |
| Acute renal failure | 38 (8.6) | 5 (6.0) | 11 (9.4) | 7 (9.0) | 15 (9.2) | |
| Readmission within 30 days¶ | 72 (16.3) | 15 (17.9) | 22 (18.8) | 12 (15.4) | 23 (14.1) | |
| Hospital length of stay (days) [mean (SD)] | 6.6(4.1) | 5.7(1.7) | 7.0(4.6) | 7.5(6.5) | 6.4(2.8) | 0.036 |

[23 (7, 54) *vs* 18 (6, 50); rank-sum test, *P*=0.309]. Similarly, among those undergoing laparoscopic procedures, AHI did not differ significantly between those who experienced any complication *vs* not [11 (4, 36) *vs* 10 (4, 24); rank-sum test, *P*=0.296], and also did not differ significantly between those who experienced pulmonary complications *vs* not [14 (6, 58) *vs* 10 (4, 26); rank-sum test, *P*=0.374].

Logistic regression was used to assess the multivariable association of OSA category, age, sex, BMI, and surgical approach with postoperative complications (Table 4). Separate analyses were performed for any complication, pulmonary complications, operative complications, and other complications. For all categories of complications, the likelihood was increased with open *vs* laparoscopic procedures. Increased BMI and age were associated with increased likelihood of pulmonary and other complications. Considering all factors evaluated, the likelihood of complications was not associated with OSA category (all *P*>0.60). To supplement the overall analyses, the multivariable models were also fitted separately for open and laparoscopic procedures, and considering all factors evaluated, no association was detected between OSA category and postoperative complications (data not shown).

The duration of hospitalization is presented separately for patients undergoing open (Table 2) and laparoscopic (Table 3) procedures. From univariate analysis, there was some evidence (*P*=0.036), indicating that the duration of stay differed among OSA categories in patients undergoing open procedures; however, the observed differences were not associated with increasing OSA severity. From a multiple

**Table 3** Postoperative complications and duration of hospital stay among patients undergoing laparoscopic procedures. CPAP, continuous positive airway pressure; PACU, postoperative anesthesia care unit. *OSA categories are defined by AHI as none (≤4), mild (5–15), moderate (16–30), and severe (≥31); †Data are compared across OSA groups using the $\chi^2$ test for complications and ANOVA for duration of stay. When the frequency of complications was compared across OSA treated as a dichotomous variable (none *vs* mild, moderate, or severe), no significant differences were found ($P$=0.783, 0.646, 0.778, and 0.880 for at least one complication, pulmonary complication, surgical complication, and other complication, respectively). Because some patients experienced multiple complications, the overall rate for a given category is less than the sum of the individual complications. ‡Initiation of CPAP in patients who did not have it before operation. ¶Although hospital readmission is included in the 'other complication' category, a pulmonary complication (e.g. pneumonia) or surgical complication (e.g. wound infection) may have been the reason for readmission

| | Total ($n$=355) | Obstructive sleep apnoea category* | | | | $P$-value† |
|---|---|---|---|---|---|---|
| | | 1=none ($n$=95) | 2=mild ($n$=130) | 3=moderate ($n$=49) | 4=severe ($n$=81) | |
| At least one complication [$n$ (%)] | 86 (24.2) | 24 (25.3) | 24 (18.5) | 13 (26.5) | 25 (30.9) | 0.213 |
| Pulmonary complications [$n$ (%)] | 14 (3.9) | 3 (3.2) | 4 (3.1) | 2 (4.1) | 5 (6.2) | 0.687 |
| Respiratory arrest | 1 (0.3) | 0 (0.0) | 1 (0.8) | 0 (0.0) | 0 (0.0) | |
| Bronchitis/pneumonia | 5 (1.4) | 1 (1.1) | 2 (1.5) | 1 (2.0) | 1 (1.2) | |
| Ventilatory support beyond PACU | 7 (2.0) | 1 (1.1) | 2 (1.5) | 0 (0.0) | 4 (4.9) | |
| Initiation of CPAP‡ | 1 (0.3) | 0 (0.0) | 0 (0.0) | 1 (2.0) | 0 (0.0) | |
| Need for tracheal reintubation | 5 (1.4) | 1 (1.1) | 3 (2.3) | 0 (0.0) | 1 (1.2) | |
| Surgical complications [$n$ (%)] | 44 (12.4) | 11 (11.6) | 15 (11.5) | 5 (10.2) | 13 (16.0) | 0.715 |
| Bleeding | 20 (5.6) | 3 (3.2) | 8 (6.2) | 5 (10.2) | 4 (4.9) | |
| Wound dehiscence | 4 (1.1) | 1 (1.1) | 2 (1.5) | 0 (0.0) | 1 (1.2) | |
| Anastomotic leak | 8 (2.3) | 2 (2.1) | 2 (1.5) | 0 (0.0) | 4 (4.9) | |
| Wound infection | 14 (3.9) | 3 (3.2) | 4 (3.1) | 0 (0.0) | 7 (8.6) | |
| Reoperation | 17 (4.8) | 5 (5.3) | 6 (4.6) | 1 (2.0) | 5 (6.2) | |
| Other complications [$n$ (%)] | 54 (15.2) | 14 (14.7) | 14 (10.8) | 10 (20.4) | 16 (19.8) | 0.228 |
| Death | 1 (0.3) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 1 (1.2) | |
| Myocardial infarction | 2 (0.6) | 0 (0.0) | 1 (0.8) | 0 (0.0) | 1 (1.2) | |
| Dysrhythmia | 8 (2.3) | 2 (2.1) | 2 (1.5) | 2 (4.1) | 2 (2.5) | |
| Stroke | 1 (0.3) | 1 (1.1) | 0 (0.0) | 0 (0.0) | 0 (0.0) | |
| Thromboembolic† | 1 (0.3) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 1 (1.2) | |
| Severe sepsis | 1 (0.3) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 1 (1.2) | |
| Liver failure | 1 (0.3) | 1 (1.1) | 0 (0.0) | 0 (0.0) | 0 (0.0) | |
| Acute renal failure | 13 (3.7) | 1 (1.1) | 4 (3.1) | 4 (8.2) | 4 (4.9) | |
| Readmission within 30 days¶ | 40 (11.3) | 12 (12.6) | 9 (6.9) | 8 (16.3) | 11 (13.6) | |
| Hospital length of stay (days) [mean (SD)] | 3.7 (3.2) | 4.1 (4.7) | 3.4 (2.5) | 3.4 (1.5) | 4.0 (2.8) | 0.305 |

linear regression model that included OSA category, age, sex, BMI, and surgical approach as explanatory variables, a greater duration of hospital stay was found to be associated with open *vs* laparoscopic procedures ($P$<0.001) and with greater BMI ($P$=0.020). From this multivariable model, no association was found between hospital duration of stay and OSA category ($P$=0.651).

## Discussion

Among the multiple co-morbidities associated with morbid obesity that may increase perioperative risk, OSA has attracted particular attention because of the potential consequences of respiratory depression and respiratory arrest. This study represents the most extensive report to date examining the impact of OSA diagnosed by strict criteria on the rate of perioperative complications. The main finding is that among patients undergoing bariatric surgery with recognized OSA and who received contemporary perioperative care, we did not detect an independent association between the severity of OSA and frequency of postoperative complications. The majority of patients with OSA were treated with PAP during sleep and monitored throughout the perioperative period, so these results do not provide insight into whether unrecognized (and untreated) OSA increases risk.

Existing guidelines for the perioperative care of OSA patients are based primarily on expert opinion rather than on objective evidence that OSA is actually a risk factor for perioperative complications.[8] This topic is difficult to study, because OSA is under-diagnosed, and the definitive diagnostic test (PSG) is expensive and time-consuming. Screening tests such as overnight oximetry have some clinical utility but lack diagnostic accuracy.[24] There are also wide variations among studies in the definition of 'complications', with authors including complications that are of uncertain clinical significance (e.g. atelectasis, oxyhaemoglobin desaturation,

**Table 4** Multiple logistic regression analysis of postoperative complications. Data were analysed using multiple logistic regression with the given type of complication as the dependent variable. For the analyses presented in the table, age and BMI were modelled as continuous variables, and all other characteristics were modelled as categorical variables. In multivariable models which included OSA as a dichotomous variable (any *vs* none), the frequency of complications was not found to be significantly associated with the presence of OSA (OR=0.86, 95% CI 0.58–1.29, *P*=0.476 for any complication; OR=1.00, 95% CI 0.44–2.30, *P*=0.992 for pulmonary complication; OR=1.33, 95% CI 0.79–2.25, *P*=0.284 for surgical complication; and OR=0.79, 95% CI 0.49–1.25, *P*=0.310 for other complication). In multivariable models which included AHI as a continuous variable, the frequency of any, pulmonary, and surgical complications was not found to be significantly associated with AHI (OR=0.99 per 5 unit increase, 95% CI 0.97–1.02, *P*=0.639 for any complication; OR=1.00 per 5 unit increase, 95% CI 0.97–1.04, *P*=0.892 for pulmonary complication; and OR=1.01 per 5 unit increase, 95% CI 0.98–1.04, *P*=0.406 for surgical complication) and the frequency of 'other' complications was found to decrease significantly with increasing AHI (OR=0.97 per 5 unit increase, 95% CI 0.94–1.00, *P*=0.044). †OSA categories are defined by AHI as none (AHI≤5), mild (6≤AHI≤15), moderate (16≤AHI≤30), and severe (AHI≥31)

| Model effect | Any complication | | | Pulmonary complication | | | Surgical complication | | | Other complication | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | OR | 95% CI | *P*-value | OR | 95% CI | *P*-value | OR | 95% CI | *P*-value | OR | 95% CI | *P*-value |
| OSA category† | | | 0.844 | | | 0.701 | | | 0.728 | | | 0.618 |
| None | 1.00 | — | | 1.00 | — | | 1.00 | — | | 1.00 | — | |
| Mild | 0.9 | 0.58, 1.39 | | 0.90 | 0.36, 2.25 | | 1.39 | 0.79, 2.45 | | 0.83 | 0.50, 1.39 | |
| Moderate | 0.88 | 0.52, 1.49 | | 1.38 | 0.52, 3.63 | | 1.24 | 0.63, 2.43 | | 0.83 | 0.45, 1.52 | |
| Severe | 0.80 | 0.50, 1.30 | | 0.92 | 0.36, 2.35 | | 1.30 | 0.71, 2.40 | | 0.68 | 0.39, 1.20 | |
| Age (per 10 yr) | 1.28 | 1.10, 1.49 | 0.001 | 1.82 | 1.38, 2.41 | <0.001 | 1.12 | 0.94, 1.35 | 0.21 | 1.28 | 1.07, 1.52 | 0.006 |
| Sex | | | 0.293 | | | 0.756 | | | 0.733 | | | 0.08 |
| Male | 1.00 | — | | 1.00 | — | | 1.00 | — | | 1.00 | — | |
| Female | 0.82 | 0.57, 1.19 | | 0.90 | 0.48, 1.71 | | 1.08 | 0.68, 1.71 | | 0.69 | 0.45, 1.05 | |
| BMI (per 5 kg $m^{-2}$) | 1.19 | 1.09, 1.30 | <0.001 | 1.35 | 1.17, 1.56 | <0.001 | 1.11 | 1.00, 1.23 | 0.053 | 1.12 | 1.01, 1.24 | 0.025 |
| Procedure | | | <0.001 | | | <0.001 | | | 0.021 | | | 0.021 |
| Open | 1.00 | — | | 1.00 | — | | 1.00 | — | | 1.00 | — | |
| Laparoscopic | 0.56 | 0.41, 0.77 | | 0.46 | 0.24, 0.88 | | 0.62 | 0.41, 0.93 | | 0.64 | 0.44, 0.94 | |

and the need for supplemental oxygen). Also, the catastrophic complications of greatest interest such as respiratory arrest are rare and would require a very large series to study.

Another consideration complicating the study of how OSA may contribute to perioperative risk relates to the distinction between OSA per se and other forms of sleep-disordered breathing. We show that a number of patients treated with CPAP before operation did not meet criteria for OSA but rather were diagnosed with UARS, another form of sleep-disordered breathing characterized by increased upper airway resistance without frank apnoea and absence of decreases in arterial oxygenation.[25 26] UARS is associated with many of the symptoms of OSA (e.g. excessive daytime sleepiness) and may respond to CPAP. Whether this syndrome is a distinct entity or merely a continuum of the OSA syndrome remains controversial;[25 26] however, the AASM considers UARS most likely a part of continuum of the OSA disease process, and the latest sleep nosology (International Classification of Sleep Disorders, 2nd edition) recommends abandoning the term UARS and recommends including these patients under the term OSA.[27] The criteria for the diagnosis of UARS, however, remain controversial, and it is not known if UARS is associated with the same serious co-morbidities as OSA. Thus, not all patients with sleep-disordered breathing have OSA, which may complicate the interpretation of studies that do not use PSG to confirm OSA diagnosis.

Recognizing these limitations, only a few studies have attempted to assess OSA as a risk factor for complications in non-airway surgery, and none of them specifically addresses the morbidly obese. Mooe and colleagues[11] found that OSA was associated with an increased frequency of atrial fibrillation after coronary artery bypass grafting, although they did not control for potentially relevant variables such as BMI. Gupta and colleagues[9] performed a case–control study in orthopaedic patients with OSA and found an increased risk for total, but not pulmonary, complications. Hwang and colleagues[10] found that in patients with OSA, the frequency of desaturation in preoperative overnight oximetry predicted complications, but such desaturations are not specific for OSA, and their definitions of complications included the need for supplemental oxygenation, making this association less surprising. In contrast, Sabers and colleagues[12] found that OSA was not a significant risk for unanticipated hospital admission after outpatient surgery. Recently, a large prospective, observational study of patients undergoing first-time bariatric surgery examined the risk for developing 30 day major composite outcome (death, thrombotic event, surgical re-intervention, or failure to be discharged) and the independent risks were history of deep venous thrombosis or pulmonary embolism, self-reported diagnosis of OSA, and impaired functional status.[28] Interestingly, in the multivariable model which included the other covariates, the association between self-reported OSA diagnosis and the composite endpoint did not meet the standard

criteria for statistical significance {odds ratio (OR)=1.37 [95% confidence interval (CI) 0.99, 1.91], $P$=0.06}.[28] The authors further acknowledge that their findings could not establish whether OSA is a marker of other factors predictive of an adverse outcome or rather that OSA *per se* confers an increased risk of worse outcome.

We reasoned that if recognized OSA is an independent risk factor for postoperative complications, there should be a relationship between the severity of OSA, as determined by PSG, and the rate of complications. As expected, in our cohort, patients with more severe OSA had a greater BMI, increased preoperative co-morbidities, and were more likely to be male. Nonetheless, from both univariate and multivariable analyses, there was no significant association between the severity of recognized OSA and postoperative complications in this cohort of patients managed according to the current clinical practices in our institution. Thus, either OSA is not an independent risk factor for complications or the recognition and management of OSA in the perioperative period mitigates this risk.

The limitations of this negative result must be appreciated. First, although our study included 797 patients undergoing PSG before operation, we cannot definitively conclude that there is no association between OSA severity and the rate of perioperative complications. On the basis of the upper bounds of 95% CIs (Table 4), we cannot exclude the possibility that the odds of pulmonary or surgical complications in those with OSA at least doubled compared with patients without OSA and it is possible that a larger series would find significant differences. Secondly, most patients in this series received intensive treatment and monitoring after operation, and the intensity of therapy may have increased with the severity of recognized OSA. As part of this perioperative practice, CPAP or bi-level PAP was reinstituted at admission to the PACU in all our patients who had them prescribed before operation, the continued use of devices after discharge from the PACU during sleep was enforced, and 86% of the patients were closely monitored at least for first 24 h. Thus, these findings cannot be applied to patients with unrecognized and untreated OSA. The efficacy of both CPAP or bi-level PAP and heightened postoperative monitoring in decreasing postoperative complications in patients with OSA is not known, although they represent an effective means in preventing post-extubation respiratory failure in medical[29] and surgical[30] populations. Also, it is likely that any substantial respiratory depression would be diagnosed quickly and treated in these intensively monitored settings. Thirdly, these results cannot determine whether OSA per se increases perioperative risk, because most of the patients in this series had some form of sleep-disordered breathing and were receiving treatment, including some who did not meet criteria for OSA. Fourthly, these results may not apply to those patients who are not morbidly obese, those undergoing other types of operative procedures, or those not receiving intense postoperative monitoring in a tertiary care centre. Finally, to avoid confounding based on differences in PSG techniques, we studied only patients who had their PSG done at Mayo Clinic, a potential source of selection bias.

Complications of bariatric surgery include pulmonary, cardiovascular, thromboembolic, and surgical (e.g. anastomotic leaks, wound infections, and bowel obstruction) events.[31] The definition of a 'complication' in the present study was chosen both to be consistent with our prior definitions and to be clinically relevant (e.g. the need for supplemental oxygen and 'atelectasis' included often in other definitions of pulmonary complications were not defined as complications in this study). In the last decade, laparoscopic approaches have gained in popularity as a means to perhaps decrease the complication rates.[21 32] In the present study, we confirmed that laparoscopic operations were associated with a lesser complication rate (Table 4). The reduction in surgical complications appears to be due to a lower incidence of wound infection and dehiscence (Tables 2 and 3). Laparoscopic techniques were also associated with a shorter hospital stay (6.6 *vs* 3.7 days). However, the choice of surgical approach was not randomized nor evenly distributed among these patients (e.g. BMI was greater in patients receiving open operations), so that not all differences in outcome can be attributed to operative approach alone. Other reported factors increasing risk in bariatric surgery include older age, male sex,[5 22] and BMI,[3–5] some of which were confirmed in the present study. The overall complication rate, including mortality, in the present study is similar to that of other large series.[31] Concern has been raised regarding whether the use of positive airway pressure may cause bowel distension leading to subsequent anastomotic leaks.[33] CPAP or bi-level PAP has, however, been used safely in large bariatric series,[19 34] and only 2% of our patients developed anastomotic leaks, which is within the range of the reported rate for this specific complication in bariatric surgery.[21 35]

In conclusion, in morbidly obese patients who were evaluated before bariatric operation by PSG at an academic tertiary care centre where the use of postoperative non-invasive ventilation is nearly universal, the severity of OSA as assessed by the AHI was not associated with the rate of perioperative complications. Our results cannot determine whether unrecognized and untreated OSA increases perioperative risk.

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## Conflict of interest

None declared.

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