ORIGINAL CLINICAL RESEARCH REPORT

OPEN CME

# Preoperative Atelectasis in Patients with Obesity Undergoing Bariatric Surgery: A Cross-Sectional Study

Javier Mancilla-Galindo, MBBS, MSc,* Jesus Elias Ortiz-Gomez, MD,† Orlando Rubén Pérez-Nieto, MD,‡ Audrey De Jong, MD, PhD,§ Diego Escarramán-Martínez, MD, MSc,‖ Ashuin Kammar-García, PhD,¶ Luis Carlos Ramírez Mata, MD,# Adriana Mendez Díaz, MD,** and Manuel Alberto Guerrero-Gutiérrez, MD**

**BACKGROUND:** Pulmonary atelectasis is present even before surgery in patients with obesity. We aimed to estimate the prevalence and extension of preoperative atelectasis in patients with obesity undergoing bariatric surgery and to determine if variation in preoperative $Spo_2$ values in the seated position at room air is explained by the extent of atelectasis coverage in the supine position.

**METHODS:** This was a cross-sectional study in a single center specialized in laparoscopic bariatric surgery. Preoperative chest computed tomographies were reassessed by a senior radiologist to quantify the extent of atelectasis coverage as a percentage of total lung volume. Patients were classified as having atelectasis when the affection was ≥2.5%, to estimate the prevalence of atelectasis. Crude and adjusted prevalence ratios (aPRs) and odds ratios (aORs) were obtained to assess the relative prevalence of atelectasis and percentage coverage, respectively, with increasing obesity category. Inverse probability weighting was used to assess the total, direct (not mediated), and indirect (mediated through atelectasis) effects of body mass index (BMI) on preoperative $Spo_2$, and to quantify the magnitude of mediation (proportion mediated). E-values were calculated, to represent the minimum magnitude of association that an unmeasured confounder with the same directionality of the effect should have to drive the observed point estimates or lower confidence intervals (CIs) to 1, respectively.

**RESULTS:** In 236 patients with a median BMI of 40.3 kg/m$^2$ (interquartile range [IQR], 34.6–46.0, range: 30.0–77.3), the overall prevalence of atelectasis was 32.6% (95% CI, 27.0–38.9) and by BMI category: 30 to 35 kg/m$^2$, 12.7% (95% CI, 6.1–24.4); 35 to 40 kg/m$^2$, 28.3% (95% CI, 17.2–42.6); 40 to 45 kg/m$^2$, 12.3% (95% CI, 5.5–24.3); 45 to 50 kg/m$^2$, 48.4% (95% CI, 30.6–66.6); and ≥50 units, 100% (95% CI, 86.7–100). Compared to the 30 to 35 kg/m$^2$ group, only the categories with BMI ≥45 kg/m$^2$ had significantly higher relative prevalence of atelectasis—45 to 50 kg/m$^2$, aPR = 3.52 (95% CI, 1.63–7.61, E-value lower bound: 2.64) and ≥50 kg/m$^2$, aPR = 8.0 (95% CI, 4.22–15.2, E-value lower bound: 7.91)—and higher odds of greater atelectasis percentage coverage: 45–50 kg/m$^2$, aOR = 7.5 (95% CI, 2.7–20.9) and ≥50 kg/m$^2$, aOR = 91.5 (95% CI, 30.0–279.3). Atelectasis percent alone explained 70.2% of the variation in preoperative $Spo_2$. The proportion of the effect of BMI on preoperative $Spo_2$ values <96% mediated through atelectasis was 81.5% (95% CI, 56.0–100).

**CONCLUSIONS:** The prevalence and extension of atelectasis increased with higher BMI, being significantly higher at BMI ≥45 kg/m$^2$. Preoperative atelectasis mediated the effect of BMI on $Spo_2$ at room air in the seated position. (Anesth Analg 2025;140:1450–60)

From the *Institute for Risk Assessment Sciences, Utrecht University, Utrecht, Netherlands; †Department of Bariatric Surgery, Baja Hospital and Medical Center, Tijuana, Mexico; ‡Department of Intensive Care Medicine, Hospital General San Juan del Rio, Queretaro, Mexico; §Department of Anesthesia and Intensive Care Unit, Regional University Hospital of Montpellier, St-Eloi Hospital, University of Montpellier, Montpellier, France; ‖Department of Anesthesia, National Medical Center "La Raza," Mexico City, Mexico; ¶Dirección de Investigación, Instituto Nacional de Geriatría, Mexico City, Mexico; #Department of Radiology, Baja Hospital and Medical Center, Tijuana, Mexico; and **Department of Bariatric Anesthesia, Baja Hospital and Medical Center, Tijuana, Mexico.

Accepted for publication June 25, 2024.



DOI: 10.1213/ANE.0000000000007166

**Conflicts of Interest, Funding:** Please see DISCLOSURES at the end of this article.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's website (www.anesthesia-analgesia.org).

Posted History: This article was previously posted to medRxiv: https://doi.org/10.1101/2024.01.11.24301138.

Data Availability: The data that support the findings of this study are openly available in the Harvard Dataverse at https://doi.org/10.7910/DVN/4JZZLB.

Code Availability: The code documenting the analysis in this study is openly available in https://github.com/javimangal/preoperative-atelectasis, and deposited in https://zenodo.org/doi/10.5281/zenodo.10211241.

Reprints will not be available from the authors.

Address correspondence to Manuel Alberto Guerrero-Gutiérrez, MD, Department of Bariatric Anesthesia, Baja Hospital and Medical Center, Ernesto Sarmiento 2308, Burócrata, Ruiz Cortines, Tijuana 22046, Baja California, México. Address e-mail to manuelguerreromd@gmail.com.

**KEY POINTS**

- **Question:** What is the prevalence of preoperative atelectasis in patients undergoing bariatric surgery and are changes in the preoperative peripheral saturation of oxygen ($Spo_2$) at room air in the seated position explained by the extent of atelectasis coverage on chest computed tomography (CT) in the supine position?
- **Findings:** Preoperative atelectasis were highly prevalent (32.6%, 95% confidence interval [CI], 27.0–38.9) in patients with obesity. A body mass index (BMI) >45 kg/m$^2$ was associated with a higher relative prevalence and atelectasis percentage coverage, the latter of which alone explained 70.2% of the variation in $Spo_2$, with 81.5% (95% CI, 56.0–100) of the effect of BMI on $Spo_2$ <96% mediated through atelectasis.
- **Meaning:** Pulmonary atelectasis is detectable before surgery in obese patients and largely explains decreased preoperative $Spo_2$ values, which could be an important factor to consider when interpreting postoperative atelectasis and for deciding perioperative ventilation strategies.

North American countries have a high prevalence of obesity in adults: United States,[1] 41.9%; Canada,[2] 30.0%; and Mexico,[3] 36.9%. People living with obesity are more susceptible to complications during the perioperative period due to factors such as reduced functional residual capacity, cephalic displacement of the diaphragm, and increased adipose tissue in the chest wall and abdomen.[4,5] Increasing body mass index (BMI) is associated with a greater decline in lung vital capacity during anesthesia.[6]

Obesity is an important risk factor for lung complications (ie, atelectasis) in patients undergoing anesthesia, as these patients suffer from mechanical compression (leading to airway narrowing and closure), obstructive sleep apnea (OSA), and obesity hypoventilation syndrome.[7] Perioperative atelectasis is more common in patients with obesity compared to patients with a normal BMI, with the former experiencing persistence of atelectasis 24 hours after surgery.[8] Although attention has focused on postoperative atelectasis, Lagier et al[9] recently highlighted that "the direct impact of intraoperative pulmonary atelectasis on postoperative outcomes is still unclear."

Besides the previously mentioned mechanisms, altered lung surfactant production induced by obesity could cause atelectasis, as animal models with obesity have demonstrated surfactant deficiency relative to alveolar surface area.[10,11] Obese patients with asthma have reduced surfactant protein (SP)-A levels,[12] a mechanism that could increase surface tension, thereby facilitating alveolar collapse.[13] Notably, weight loss after bariatric surgery has been shown to improve lung function due to the normalization of SP-A and SP-C expression.[14]

Despite being less studied, atelectasis occurs even before surgery in patients with obesity.[8,15] Our hypotheses were that the occurrence of atelectasis increases with a higher degree of obesity and that the biological effect of BMI on preoperative peripheral saturation of oxygen ($Spo_2$) is mediated by atelectasis, despite these measurements being taken in different positions (seated versus supine). Thus, the objective of this study was to assess the prevalence and extension of preoperative atelectasis (primary outcome) in patients with increasing degrees of obesity (exposure) and to assess the extent to which the effect of BMI on $Spo_2$ (secondary outcome) is mediated through atelectasis.

## METHODS

### Study Design and Setting

This was a single-center cross-sectional study conducted in a specialized center for laparoscopic bariatric surgery in Tijuana, Mexico mainly receiving patients from abroad. The study period was the month of June 2020. Adult patients who presented for elective bariatric surgery and underwent chest computed tomography (CT) scan screening for coronavirus disease-2019 (COVID-19) were eligible. Exclusion criteria were a positive antibody test against severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), prior history of COVID-19, neuromuscular disease, bronchiectasis, and a COVID-19 Reporting and Data System (CO-RADS)[16] score of 3 to 6 (level of suspicion for pulmonary involvement of COVID-19 on chest CT, where 3 is assigned when there are features compatible with COVID-19, scores 4 and 5 represent increasing suspicion, and 6 means proven COVID-19). This study was reviewed and approved by the ethics committee of Hospital General de Tijuana (CONBIOÉTICA-02-CEI-001-20170526, approval number 001771) and the requirement for written informed consent was waived by the IRB. Greater details on the COVID-19 screening algorithm, study setting, and sample size estimation are provided as Supplemental Digital Content 1, Supplemental Methods, http://links.lww.com/AA/E960.

### Exposure

Weight was measured on a 90 cm × 90 cm platform scale (Rhino PLABA-9) with maximal capacity of 1000 kg and 200 grams precision. For height determination, patients are encouraged to stand with the heels together and buttocks, shoulders, and head in contact with a stadiometer (precision 0.1 mm). BMI (kg/m$^2$) was calculated as the ratio of weight (kg) and squared height (m$^2$). The World Health Organization (WHO) obesity class categories[17] were as follows: class 1 (30–35 kg/m$^2$), 2 (35–40 kg/m$^2$), and 3 (≥40 kg/m$^2$). Class 3 obesity subgroups were defined as: 40–45 kg/m$^2$, 45–50 kg/m$^2$, and ≥50 units.

### Outcomes

The main outcome was the prevalence of atelectasis. Secondary outcomes were the degree of atelectasis coverage as a percentage of lung volume and $Spo_2$ during the preanesthetic assessment.

High-resolution chest CT images (1mm slices, 120 kV, 50 mA, scan time: 0.5 seconds, field of view length L: 240) were obtained with a Toshiba Aquilion 16 Slice CT Scanner and archived in EvoView Picture Archiving and Communication System (U.M.G. Inc). A senior radiologist blinded to the patient's BMI assessed the presence and extent of atelectasis (OsiriX viewer) by measuring the total area of the lung—pixels with density values between –1000 and +100 Hounsfield Units (HU). Densities considered to indicate atelectasis were identified in dependent lung regions and calculated by including all pixels —HU between –100 and +100.[18] Because a median atelectasis percentage coverage of 2.5% has been shown to have low-to-no impact on oxygenation,[19] percentage of atelectasis coverage was registered by rounding to the lower 2.5% category (ie values <2.5% were rounded to 0%). Thus, all patients with an atelectasis percentage ≥2.5% were classified as having atelectasis. Predominance of atelectasis on chest CT was recorded as right lung base predominance or bilateral lung bases affection.

$Spo_2$ was determined during the preanesthetic assessment with the patient seating, at rest, at room air (FiO2: 21%) with a pulse oximeter (Masimo SET, precision 2% in the 70% to 100% range).

### Confounders

Hypothesized relationships between exposure, mediators, outcomes, and confounders were defined a priori and schematized in a directed acyclic graph (DAG) with the *DAGitty* software[20] according to published literature (Supplemental Digital Content 1, Supplemental Methods, http://links.lww.com/AA/E960). The diagram was updated by testing implied conditional independencies as described by Ankan et al[21] (Supplemental Digital Content 2, Supplemental Figure 1, http://links.lww.com/AA/E961).

Age, sex, and mean altitude of the state of residence in meters above sea level (m.a.s.l.) constituted the minimal set of adjustment for the relationship between obesity class and atelectasis. For the relationship between BMI and preoperative $Spo_2$, atelectasis percentage was studied as the mediator of the effect. The minimal set of confounders for BMI→$Spo_2$ was the same as above, whereas the set of confounders for atelectasis→$Spo_2$ were age, sex, BMI, altitude, asthma, OSA, and chronic obstructive pulmonary disease (COPD; Supplemental Digital Content 3, Supplemental Figures 2A and 2B, http://links.lww.com/AA/E962). These were used for the obtention of inverse probability weights (IPWs) to allow the estimation of direct and indirect effects of BMI as illustrated in Supplemental Digital Content 3, Supplemental Figures 2C and 2D, http://links.lww.com/AA/E962.

Comorbidities (acute myocardial infarction, tuberculosis, asthma, COPD, OSA, systemic arterial hypertension, diabetes mellitus, hypothyroidism, dyslipidemia, use of antidepressants, and prior COVID-19) and the use of supplementary oxygen at home were extracted from medical records and registered as positive if self-reported by patients in a self-administered questionnaire at admission, or if recorded in the preoperative assessment medical note. All participants with OSA self-reported using continuous positive airway pressure (CPAP) during sleep. Altitude was categorized into low (0–1000 m.a.s.l.) and moderate (1000–2500 m.a.s.l.) altitude[22] due to overspread distribution and inability to model altitude as a nonlinear term. Detailed descriptions of all variables are published alongside the dataset elsewhere.[23]

### Statistical Analysis

Methods for descriptive analyses and hypothesis testing are detailed in Supplemental Digital Content 1, Supplemental Methods, http://links.lww.com/AA/E960. The prevalence of atelectasis with 95% confidence interval (95% CI) was estimated with a 1-sample proportion test with Wilson score intervals for the total sample and BMI categories. Due to zero-inflation and skewness, mean atelectasis percentage was determined by bootstrapping with 10,000 resamples, and 95% CI obtained with the bias-corrected and accelerated (BCa) method. Prevalence ratios (PRs) of atelectasis per obesity class (reference category: class 1) were estimated with a modified Poisson regression model with robust errors as described by Yorlets et al[24] and adjusted for age, sex, and altitude. Sensitivity analyses were done by calculating point estimate and lower bound E-values,[25] which represent the minumum magnitude of association that an unmeasured confounder with the same directionality of the effect (meaning that the sign of the product of the counfounder's relationship with exposure and outcome is the same as that of the association between exposure and outcome) should have to drive the observed point estimates or lower CIs to 1, respectively.

Atelectasis percentage coverage was modeled in an ordinal logistic regression model.[26] Despite obesity class not meeting the proportional odds assumption, its impact was checked by comparing against partial proportional odds and multinomial models.[27] Since the AIC and McFadden adjusted R2 were better for the main proportional odds model,[28] results of ordinal logistic regression models are presented. Estimates are summarized as the unadjusted and adjusted odds ratio (aOR) with Wald 95% CI.

Mean $Spo_2$ was modeled through fractional regression with generalized additive models[29] with a quasibinomial logit link function to assess the extent to which BMI and atelectasis percentage explained the variation in $Spo_2$. IPW[30] was used to estimate the total effect of BMI on $Spo_2$ in a first model, and the direct (not mediated by atelectasis) and indirect (mediated by atelectasis) effects of BMI on $Spo_2$ in a second model. For the first model, weights ($w1$) were obtained for the exposure-outcome confounders through the nonparametric covariate balancing propensity score (npCBPS) method. For the second model, weights ($w2$) for the mediator-outcome confounders were also obtained with npCBPS and multiplied by $w1$, resulting in overall weights ($w$) used in the model. Since the relationship between exposure-outcome and mediator-outcome was nonlinear, the average total, direct, and indirect effects on mean $Spo_2$ value are shown as splines, along with their 95% CI. Goodness-of-fit is shown as the percentage explained deviance (% deviance). Nine influential outliers were removed according to a Cook's distance >4/n for the 2 main explanatory variables (BMI n = 3, atelectasis percentage n = 6); results of analyses keeping all observations can be found elsewhere.[28]

Data were split into $Spo_2$ ≤95% and >95% and modeled separately. In the $Spo_2$ ≤95% subset, the relationships between variables were close to linear, thus allowing estimation of linear effects in a generalized linear model (quasibinomial logit link function), presented as the OR for a change in mean $Spo_2$ for every unit of increase in BMI and atelectasis percentage. The proportion mediated was estimated with the formula $PM = 1 - \frac{direct\ effect}{total\ effect}$ and presented as a percentage. Bootstrap BCa 95% CI for the PM and OR were obtained by refitting the models in 10,000 resamples.

Predicted values of $Spo_2$ for all possible combinations of atelectasis percentage and BMI (within the ranges observed in this study) were obtained from the initial nonlinear $Spo_2$ models. The relationship between these 3 variables was visualized in a 3-dimensional plot and predicted curves for every unit-decrease in $Spo_2$ were plotted in a 2-dimensional plot. Observed $Spo_2$ values were plotted on top of the gradient of predictions to visualize the range at which combinations are likely to be observed in clinical practice.

Complete-case analysis was performed since missing data was <3% for all variables. Statistical significance was defined as $P < .05$. $P$-values are shown rounded to 3 decimals. All analyses and figures were created with R version 4.3.3. The dataset,[23] code,[28] and reports documenting these analyses with references of all R packages used and versions are available at https://github.com/javimangal/preoperative-atelectasis/.

## RESULTS

Out of 281 patients scheduled for surgery, 236 (84%) were included for analysis. The attrition diagram of patients included and reasons for exclusion is presented in Supplemental Digital Content 4, Supplemental Figure 3, http://links.lww.com/AA/E963. All participants were residents of the United States and Canada (Supplemental Digital Content 5, Supplemental Figure 4, http://links.lww.com/AA/E964). The mean age of participants was 40.3 years (standard deviation [SD], 9.87) years and 90.7% were female (n = 214). Most patients had a CO-RADS score of 1 (n = 230, 97.5%), while the remaining 2.5% (n = 6) had CO-RADS 2. Patients with a diagnosis of OSA constituted 14% (n = 33) of the sample. The median BMI was 40.3 kg/m$^2$ (interquartile range [IQR], 34.6–46.0, range: 30.0–77.3). Most patients were in the class 3 obesity category (n = 120, 50.8%), followed by class 1 (n = 63, 26.7%) and 2 (n = 53, 22.5%). Characteristics of the sample stratified by obesity class are shown in Table 1. Pairwise comparisons among independent variables are provided in the reports available in the GitHub repository.[28]

### Preoperative Atelectasis

The overall prevalence of preoperative atelectasis was 32.6% (95% CI, 27.0–38.9), being greater in higher obesity classes ($P < .001$): class 1 (n = 8/63), 12.7% (95% CI, 6.1–24.4); class 2 (n = 15/53), 28.3% (95% CI, 17.2–42.6); and class 3 (n = 54/120), 45.0% (95% CI, 35.7–53.9). Of those who had atelectasis, right lung base predominance n = 53 (68.8%) was more frequent compared to bilateral lung bases affection n = 24 (31.2%). When examining this by obesity class, 87.5%, 66.7%, and 66.7% had right lung base predominance in class 1, 2, and 3 categories, respectively ($P = .484$). Atelectasis percentage showed a nonmonotonic nonlinear relationship with BMI (Figure 1A). A marked increase in atelectasis percentage occurred at BMI higher than ~45 kg/m$^2$. The mean atelectasis percentage coverage in the sample was 2.66% (95% CI, 2.07–3.26) and according to WHO categories: class 1 (0.91%, 95% CI, 0.32–1.71), class 2 (1.55%, 95% CI, 0.75–2.45), and class 3 (4.06%, 95% CI, 3.1–5.08). Within class 3 subgroups, the mean atelectasis percentage was 0.7% (95% CI, 0.22–1.27) in the 40–45 kg/m$^2$ group; 3.64% (95% CI, 2.18–5.08), in 45–50 kg/m$^2$; and 10.46% (95% CI, 8.83–12.5), in the ≥50 kg/m$^2$ subgroup. The relative frequencies of the extent of coverage were significantly higher with

**Table 1. Clinical Characteristics of Patients, According to WHO Obesity Categories—Class 1 (30–35 kg/m²), Class 2 (35–40 kg/m²), and Class 3 (≥40 kg/m²) Obesity**

| | Total (n = 236) | Class 1 obesity (n = 63) | Class 2 obesity (n = 53) | Class 3 obesity (n = 120) |
|---|---|---|---|---|
| Sex | | | | |
| Female | 214 (90.7%) | 60 (95.2%) | 48 (90.6%) | 106 (88.3%) |
| Male | 22 (9.3%) | 3 (4.8%) | 5 (9.4%) | 14 (11.7%) |
| Age (y) | | | | |
| Mean (SD) | 40.3 (9.87) | 42.1 (10.2) | 40.8 (9.25) | 39.1 (9.85) |
| Weight (kg) | | | | |
| Median [Q1–Q3] | 111 [97.4–130] | 89.2 [84.5–95.9] | 107 [102–112] | 128 [114–142] |
| Height (m) | | | | |
| Mean (SD) | 1.67 (0.08) | 1.67 (0.07) | 1.69 (0.09) | 1.67 (0.09) |
| BMI (kg/m²) | | | | |
| Median [Q1–Q3] | 40.3 [34.6–46.0] | 33.0 [31.5–33.8] | 38.3 [36.6–39.1] | 45.8 [42.4–51.2] |
| Surgical procedure | | | | |
| SG | 189 (80.1%) | 53 (84.1%) | 41 (77.4%) | 95 (79.2%) |
| RYGB | 6 (2.5%) | 1 (1.6%) | 1 (1.9%) | 4 (3.3%) |
| OAGB | 5 (2.1%) | 1 (1.6%) | 1 (1.9%) | 3 (2.5%) |
| LBGS | 31 (13.1%) | 5 (7.9%) | 9 (17.0%) | 17 (14.2%) |
| ARISCAT risk group | | | | |
| Low risk | 175 (74.2%) | 45 (71.4%) | 41 (77.4%) | 89 (74.2%) |
| Intermediate risk | 61 (25.8%) | 18 (28.6%) | 12 (22.6%) | 31 (25.8%) |
| CO-RADS | | | | |
| CO-RADS 1 | 230 (97.5%) | 62 (98.4%) | 51 (96.2%) | 117 (97.5%) |
| CO-RADS 2 | 6 (2.5%) | 1 (1.6%) | 2 (3.8%) | 3 (2.5%) |
| $Spo_2$ (%) | | | | |
| Median [Q1–Q3] | 96.0 [93.0–97.0] | 97.0 [95.0–97.5] | 96.0 [94.0–97.0] | 94.0 [92.0–97.0] |
| Mean altitude (m)[a] | | | | |
| Median [Q1–Q3] | 519 [519–806] | 519 [382–806] | 519 [519–885] | 519 [519–806] |
| Acute myocardial infarction | | | | |
| No | 210 (89.0%) | 62 (98.4%) | 52 (98.1%) | 96 (80.0%) |
| Yes | 26 (11.0%) | 1 (1.6%) | 1 (1.9%) | 24 (20.0%) |
| Hypertension | | | | |
| No | 177 (75.0%) | 53 (84.1%) | 40 (75.5%) | 84 (70.0%) |
| Yes | 59 (25.0%) | 10 (15.9%) | 13 (24.5%) | 36 (30.0%) |
| Diabetes | | | | |
| No | 211 (89.4%) | 58 (92.1%) | 48 (90.6%) | 105 (87.5%) |
| Yes | 25 (10.6%) | 5 (7.9%) | 5 (9.4%) | 15 (12.5%) |
| Asthma | | | | |
| No | 216 (91.5%) | 56 (88.9%) | 46 (86.8%) | 114 (95.0%) |
| Yes | 20 (8.5%) | 7 (11.1%) | 7 (13.2%) | 6 (5.0%) |
| COPD | | | | |
| No | 228 (96.6%) | 62 (98.4%) | 53 (100%) | 113 (94.2%) |
| Yes | 8 (3.4%) | 1 (1.6%) | 0 (0%) | 7 (5.8%) |
| Obstructive sleep apnea | | | | |
| No | 203 (86.0%) | 60 (95.2%) | 50 (94.3%) | 93 (77.5%) |
| Yes | 33 (14.0%) | 3 (4.8%) | 3 (5.7%) | 27 (22.5%) |
| Supplementary oxygen at home | | | | |
| No | 206 (87.3%) | 60 (95.2%) | 50 (94.3%) | 96 (80.0%) |
| Yes | 30 (12.7%) | 3 (4.8%) | 3 (5.7%) | 24 (20.0%) |
| CPAP use during sleep | | | | |
| No | 203 (86.0%) | 60 (95.2%) | 50 (94.3%) | 93 (77.5%) |
| Yes | 33 (14.0%) | 3 (4.8%) | 3 (5.7%) | 27 (22.5%) |
| Hypothyroidism | | | | |
| No | 213 (90.3%) | 56 (88.9%) | 50 (94.3%) | 107 (89.2%) |
| Yes | 23 (9.7%) | 7 (11.1%) | 3 (5.7%) | 13 (10.8%) |
| Dyslipidemia | | | | |
| No | 218 (92.4%) | 59 (93.7%) | 48 (90.6%) | 111 (92.5%) |
| Yes | 18 (7.6%) | 4 (6.3%) | 5 (9.4%) | 9 (7.5%) |
| Use of antidepressants | | | | |
| No | 142 (60.2%) | 37 (58.7%) | 33 (62.3%) | 72 (60.0%) |
| Yes | 94 (39.8%) | 26 (41.3%) | 20 (37.7%) | 48 (40.0%) |

Abbreviations: %, percentage; ARISCAT, Assess Respiratory Risk in Surgical Patients in Catalonia; BMI, body mass index; COPD, chronic obstructive pulmonary disease; CO-RADS, coronavirus disease-2019 (COVID-19) Reporting and Data System; LBGS, lap-band to gastric sleeve; OAGB, one anastomosis gastric bypass; RYGB, roux-en-Y gastric bypass; SD, standard deviation; SG, sleeve gastrectomy; $Spo_2$, peripheral saturation of oxygen; Q1, 25th percentile; Q3, 75th percentile.
[a]Mean altitude of the state of residence.

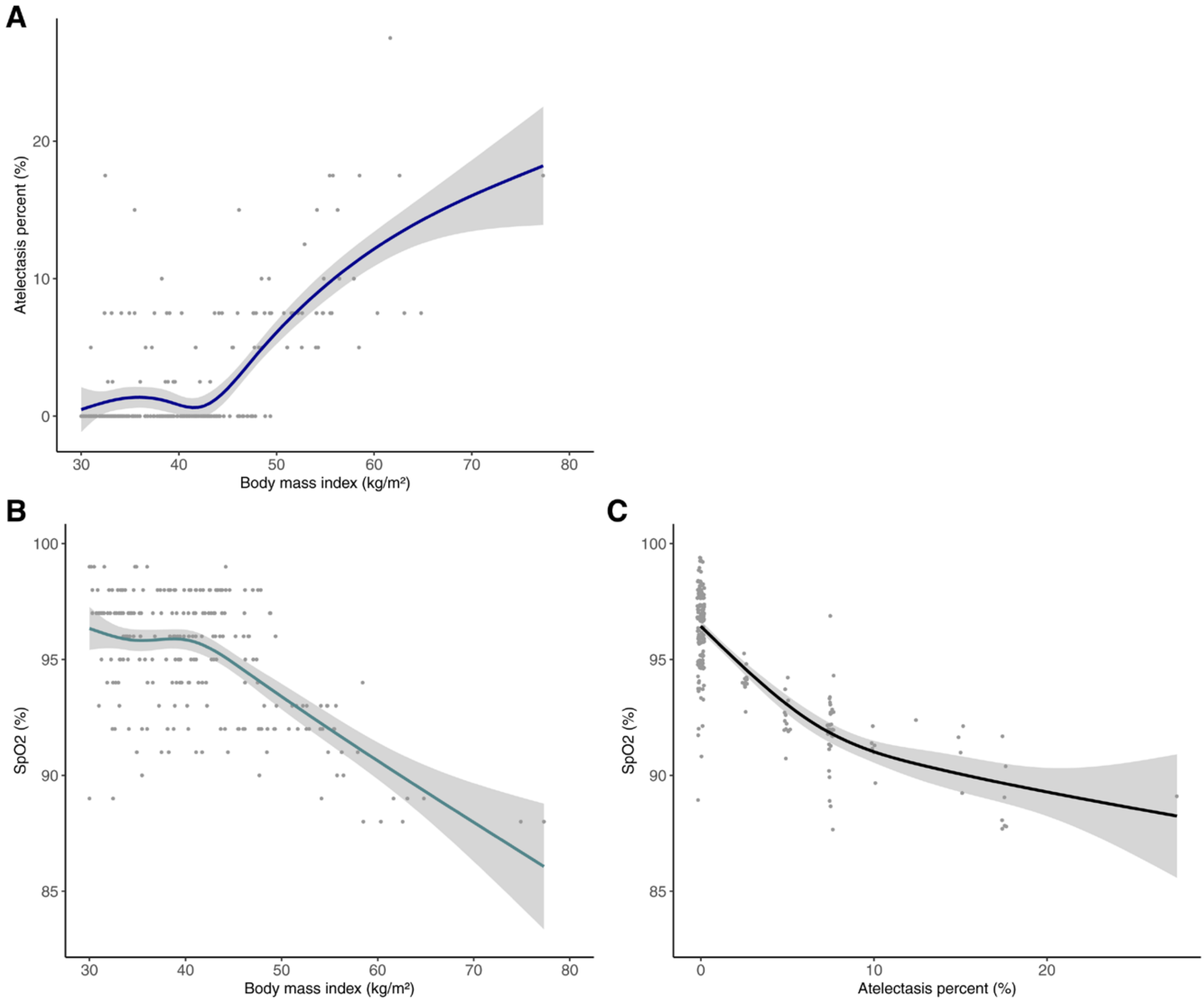


**Figure 1.** Pairwise nonlinear relationships between BMI, preoperative $Spo_2$, and preoperative atelectasis percentage coverage on chest CT scan. Dots represent individual patient observations. Curves represent the fitted smoothed nonlinear relationship. The shaded area corresponds to the 95% confidence interval. A, Atelectasis percentage as a function of BMI. B, $Spo_2$ as a function of BMI. C, $Spo_2$ as a function of atelectasis percentage. BMI indicates body mass index; CT, computed tomography; $Spo_2$, peripheral saturation of oxygen.

increasing obesity class ($P < .001$) (Supplemental Digital Content 6, Supplemental Figure 5A, http://links.lww.com/AA/E965), with greater heterogeneity and increasing percentage coverage within class 3 obesity subgroups (Supplemental Digital Content 6, Supplemental Figure 5B, http://links.lww.com/AA/E965).

Age was similarly distributed among patients without atelectasis (40.6, SD, 10.1) and those with atelectasis (39.6, SD, 9.3) ($P = .498$). The differences in atelectasis occurrence between male (45.5%) and female (31.3%) were not statistically significant ($P = .178$). Patients with a diagnosis of OSA had atelectasis more frequently (93.9%, n = 31/33) than those without (22.7%, n = 46/203) ($P < .001$). Patients with asthma tended to have atelectasis less frequently (15%) than those without the diagnosis (34.3%) ($P = .079$). Unadjusted and aPRs of atelectasis by obesity class are shown in Table 2. Compared to the 30 to 35 $kg/m^2$ group, only the categories with BMI ≥45 $kg/m^2$ had significantly higher relative prevalence of atelectasis—45 to 50 $kg/m^2$, aPR = 3.52 (95% CI, 1.63–7.61, E-value lower bound: 2.64) and ≥50 $kg/m^2$, aPR = 8.0 (95% CI, 4.22–15.2, E-value lower bound: 7.91).

Ordinal logistic regression models were fitted to assess the relationship between increasing obesity class and the extent of atelectasis percentage. The results of univariable and multivariable models are shown in Table 3. Compared to class 1 obesity, class 2 obesity was not significantly associated with a greater atelectasis percentage coverage (aOR = 2.36, 95% CI, 0.92–6.1), whereas class 3 obesity was associated with a 5-fold increase in the odds of a greater extent of atelectasis percentage (aOR = 5.87, 95% CI, 2.57–13.42).

**Table 2. Crude and Adjusted Prevalence Ratio of Atelectasis According to Obesity Class Category**

| Category | PR | 95% CI | aPR[a] | 95% CI | E-value[b] | E-value lower[c] |
|---|---|---|---|---|---|---|
| Class 1 obesity | Reference | | | Reference | | |
| Class 2 obesity | 2.23 | 1.03–4.84 | 2.17 | 1.0–4.7 | 3.76 | 1.00 |
| Class 3 obesity | 3.46 | 1.8–6.97 | 3.47 | 1.77–6.83 | 6.40 | 2.94 |
| Subgroups (Class 3 obesity) | | | | | | |
| 40–45 kg/m$^2$ | 0.97 | 0.37–2.5 | 0.85 | 0.35–2.1 | 1.63 | - |
| 45–50 kg/m$^2$ | 3.81 | 1.81–8.01 | 3.52 | 1.63–7.61 | 6.50 | 2.64 |
| ≥50 kg/m$^2$ | 7.87 | 4.12–15.05 | 8.00 | 4.22–15.17 | 15.48 | 7.91 |

Abbreviations: 95% CI, 95% confidence interval; aPR, adjusted prevalence ratio; PR, prevalence ratio.

[a]Adjusted for age, sex, and altitude category.

[b]The E-value for unmeasured confounding represents the minumum magnitude of association that an unmeasured confounder with the same directionality of the effect (meaning that the sign of the product of the counfounder's relationship with exposure and outcome is the same as that of the association between exposure and outcome) should have to drive our point estimate to a value of 1.

[c]E-value for the lower limit of the confidence interval.

Due to the heterogeneity observed in atelectasis percentage in the class 3 category, post hoc analyses were conducted to assess differences in subgroups. The prevalence of atelectasis in the 40–45 kg/m$^2$, 45–50 kg/m$^2$, and ≥50 kg/m$^2$ subgroups was 12.3% (95% CI, 5.5–24.3), 48.4% (95% CI, 30.6–66.6), and 100% (95% CI, 86.7–100), respectively. PRs and the OR for an increasing atelectasis percentage coverage are shown in Table 2 and Table 3, respectively.

### $Spo_2$ During the Preanesthetic Assessment

The median $Spo_2$ was 96% (IQR, 93–97), with a minimum value of 88%. A total n = 146 (61.9%) had normal $Spo_2$ (>94%), n = 75 (31.8%) had a value in the 90–94% range, and n = 15 (6.4%) had ≤90%. BMI exhibited a negative nonlinear nonmonotonic relationship with $Spo_2$ (Figure 1B). $Spo_2$ was significantly lower in patients with atelectasis (92%, IQR, 91–93) compared to those without (97%, IQR, 96–98) ($P$ < .001), and lower in patients with bilateral lung base atelectasis (91.5%, IQR, 90–92) compared to those with right lung predominance (92%, IQR, 92–93) ($P$ = .006). There was a decreasing trend in $Spo_2$ with higher atelectasis percentage extension (Figure 1C). Patients with OSA had a lower median $Spo_2$ (92%, IQR, 91–93) than those without (96%, IQR, 94–97) ($P$ < .001). $Spo_2$ was not correlated (rho= −0.065, $P$ = .32) with the values of hemoglobin (mean:14.5, SD, 1.21 g/dL) observed in this study. Similarly, mean altitude of the place of residence (range: 31–1861 m.a.s.l.), age (rho = 0.022, $P$ = .74), and sex ($P$ = .413) were not significantly associated with $Spo_2$.

The total effect of BMI on the mean $Spo_2$ across different values of BMI is shown in Figure 2A, while the total effect of chest CT atelectasis coverage on $Spo_2$ is shown in Figure 2C. In the IPW model including both terms, the direct effect of BMI on $Spo_2$ was significantly reduced to null when controlled for atelectasis percent (Figure 2B), whereas the effect mediated trough atelectasis (indirect effect of BMI) remained largely unchanged when compared to that not adjusted for BMI (Figure 2D), thus indicating that the effect of BMI on $Spo_2$ was largely mediated by atelectasis. Predicted $Spo_2$ values from this model are shown in Figure 3A and plotted alongside observed $Spo_2$ values (Figure 3B). The 3-dimensional relationship between $Spo_2$ predictions, BMI and atelectasis percentage is shown in Supplemental Digital Content 7, Supplemental Figure 6, http://links.lww.com/AA/E966.

Due to the observation of complete separation of residuals at a $Spo_2$ cutoff value of 95% in the prior models, data were split and modeled separately. In the >95% subset, comparisons were not possible since all participants but one had atelectasis. In the ≤95% group, relationships between variables were close to linear and the OR for the change in mean $Spo_2$ for every unit increase in BMI and atelectasis percent are provided in Supplemental Digital Content 8, Supplemental Table 1, http://links.lww.com/AA/E967. The proportion of

**Table 3. Univariable and Multivariable Ordinal Logistic Regression Models of Lung Atelectasis Percentage Coverage**

| Category | OR | 95% CI | aOR[a] | 95% CI |
|---|---|---|---|---|
| Class 1 obesity | Reference | | Reference | |
| Class 2 obesity | 2.43 | 0.95–6.22 | 2.36 | 0.92–6.1 |
| Class 3 obesity | 6.07 | 2.67–13.79 | 5.87 | 2.57–13.42 |
| Subgroups (Class 3 obesity) | | | | |
| 40–45 kg/m$^2$ | 0.97 | 0.32–2.8 | 0.89 | 0.30–2.66 |
| 45–50 kg/m$^2$ | 7.51 | 2.73–20.7 | 7.50 | 2.69–20.9 |
| ≥50 kg/m$^2$ | 86.15 | 28.8–257.8 | 91.5 | 30.0–279.3 |

An OR >1 represents increased odds of a higher atelectasis percentage coverage on chest CT with respect to the class 1 obesity category.

Abbreviations: 95% CI, 95% confidence interval; aOR; adjusted odds ratio; OR, odds ratio.

[a]Adjusted for age, sex, and altitude category.

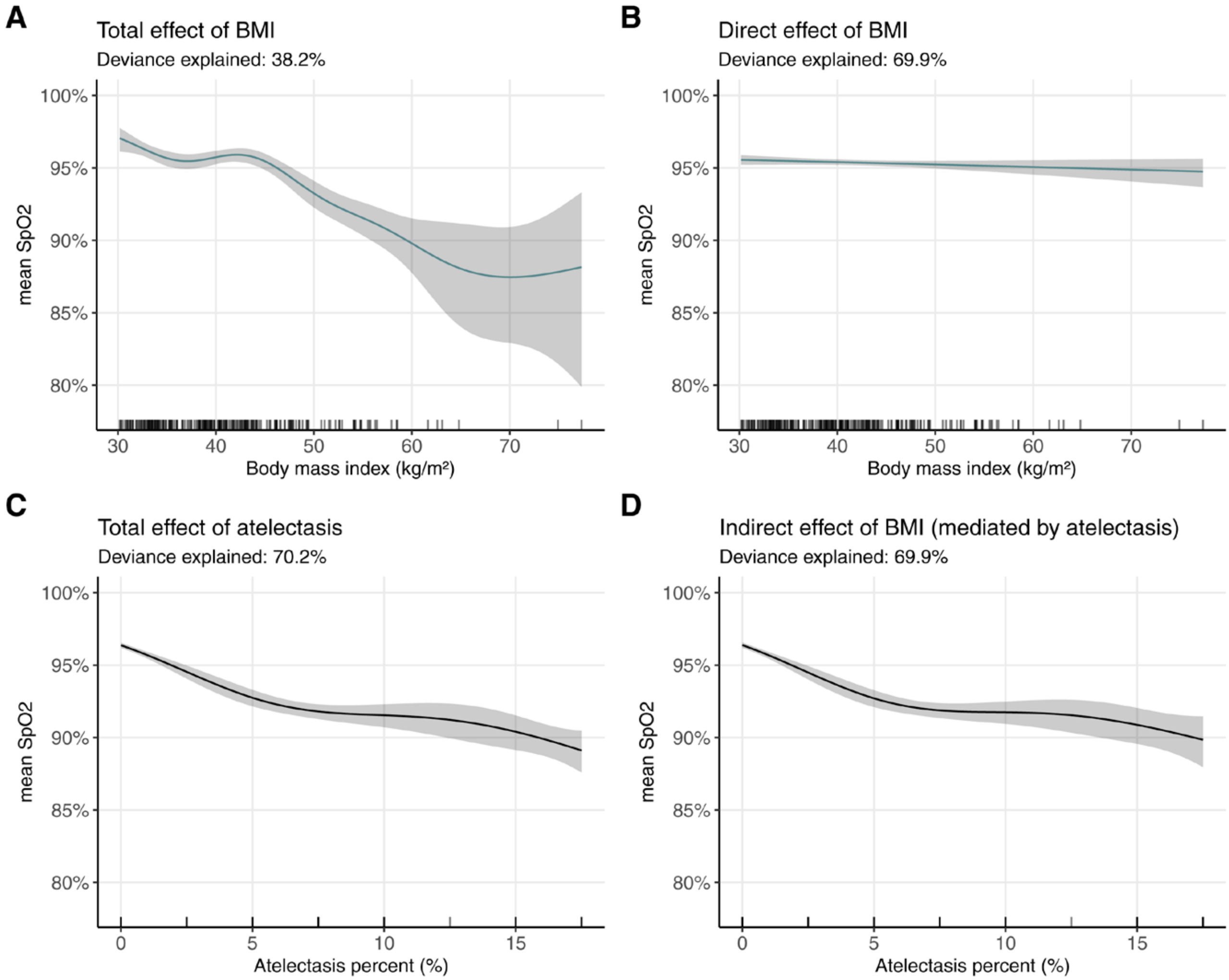


**Figure 2.** Total, direct (not mediated), and indirect (mediated through atelectasis) effects of BMI on mean $Spo_2$ during the preoperative assessment. Solid lines represent the partial effect on mean $Spo_2$ for increasing BMI (blue green) and atelectasis percent coverage on chest CT (black), with 95% confidence intervals (shaded area). Inverse probability weighted* models were used to present the following: A, Total effect of BMI in a model including only a smooth term for BMI ($P < .001$). B, Direct effect of BMI (not mediated by atelectasis), with a smooth term for BMI ($P = .182$) controlled for the effect of atelectasis. C, Total effect of atelectasis percent coverage on chest CT in a model including only a smooth term for atelectasis percent ($P < .001$). D, Indirect effect of BMI (mediated by atelectasis), with a smooth term for atelectasis percent ($P < .001$) controlled for the effect of BMI.*Inverse probability weights were obtained for the following set of variables:*w1* (age, sex, and altitude), panel A;*w2* (BMI, age, sex, altitude, obstructive sleep apnea, asthma, and COPD), panel C; and*w* (product of *w1* and *w2*), panels B and D. BMI indicates body mass index; COPD, chronic obstructive pulmonary disease; CT, computed tomography; $Spo_2$, peripheral saturation of oxygen.

the effect of BMI on $Spo_2$ mediated through atelectasis was 81.5% (95% CI, 56.0 to 100).

## DISCUSSION

Our results show a high prevalence of atelectasis in obese patients before surgery, with prevalence increasing with higher BMI. An increased risk of higher atelectasis compared to the class 1 obesity category was only confidently estimated at BMI ≥45 kg/m². Sensitivity analysis with E-values presents the minumum magnitude of association that a latent confounder with the same directionality of effect (meaning that the sign of the product of the counfounder's relationship with exposure and outcome is the same as that of the association between exposure and outcome) should have to explain these associations, showing that our results for BMI >45 kg/m² are strong estimates, since an unmeasured confounder would need to have a magnitude of association of 6.50 to drive the PR estimate to 1, or 2.64 to make the adjusted lower boundary of the CI exceed the unit. Since our study only included patients with a BMI ≥30 kg/m², it is likely that these PRs would be even higher if overweight or normal BMI were set as the reference categories, as prior studies show that atelectasis occur more frequently before surgery in obese patients than those with normal BMI.[8]

Although the prevalence of atelectasis in our study may seem high compared to other studies reporting low proportions of atelectasis in the postoperative period—for instance, 0.4% in the Bariatric Outcomes

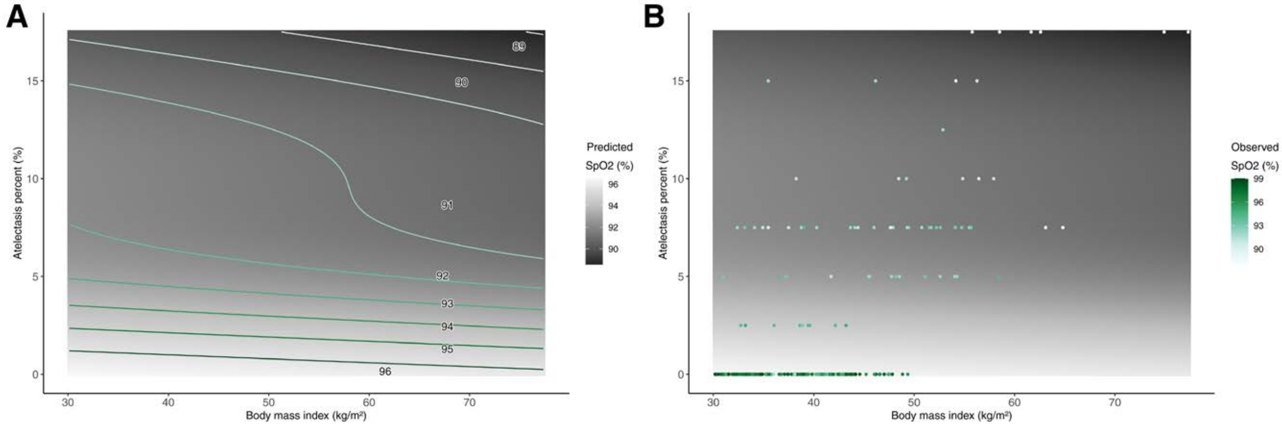


**Figure 3.** Predicted and measured $Spo_2$ values by BMI and atelectasis percentage on chest CT scan. A, Predicted $Spo_2$. Curved lines correspond to $Spo_2$ values that are predicted by BMI and atelectasis percentage. The background grid on a gray scale corresponds to predicted values of $Spo_2$ for every possible combination of atelectasis percentage and BMI, weighted for the set of variables *w* (see legend in Figure 2 for explanation). B, Observed $Spo_2$. Every dot corresponds to an individual patient observation located at the exact BMI and atelectasis percentage measured, colored according to the observed $Spo_2$ value. BMI indicates body mass index; CT, computed tomography; $Spo_2$, peripheral saturation of oxygen.

Longitudinal Database (BOLD) registry[31] and 4.4%–5.6% in the PROBESE trial,[32] atelectasis in such studies was assessed after indication of an imaging study on clinical suspicion. Therefore, patients in whom imaging is not performed are assumed to not have atelectasis, biasing estimates towards the null. Here, we propose a definition of atelectasis (≥2.5% of atelectasis coverage on chest CT as a fraction of total lung volume) which could be used in future prospective studies to homogenize outcome assessment and reporting of atelectasis.

We found a mean overall atelectasis percentage coverage (as a fraction of total lung volume) of 2.66% (95% CI, 2.07–3.26), which is close to the 2.1% reported by Eichenberger et al.[8] Lower numbers (0. 4% ± 0.7%) were reported by Reinius et al,[15] although their measurement was at the end of expiration and their estimate could be biased to the null due to zero-inflation as suggested by the SD which includes negative values. Atelectasis percentage in our study increased at higher BMI: class 1 (0.91%), class 2 (1.55%), and class 3 (4.06%).

There was a marked increase in atelectasis percentage at a cutoff close to 45 kg/m². Ordinal logistic regression analyses showed that the odds of having a higher atelectasis percentage coverage is higher in 5 to 6 orders of magnitude in the class 3 obesity category, but not statistically significant in the class 2 obesity subgroup despite the point estimate being >1 (aOR = 2.36, 95% CI, 0.92–6.1). We observed that only categories >45 kg/m² had significantly higher adjusted odds of increased atelectasis percentage coverage on chest CT. The reason why atelectasis seems to increase in class 2 obesity and then decrease again in the 40 to 45 kg/m² subgroup could be due to outliers, random variation, or residual confounding driving transient increases.

Besides the mechanisms discussed in the introduction, these findings could also be related to the significant reduction in functional residual capacity and dynamic compliance (Cdyn) due to increasing intraabdominal and intrathoracic pressure with higher BMI. This phenomenon has been shown by Steier et al[33] when comparing normal BMI to obese patients (0.135 L/cm$H_2O$ vs 0.105 L/cm$H_2O$, $P < .05$) and Li et al[34] (~0.031 L/cm$H_2O$ after intubation).

As a secondary objective, we studied the extent to which $Spo_2$ measured during the preoperative assessment could be due to BMI alone or mediated by atelectasis percentage. We showed that atelectasis alone explained 70.2% of variation in $Spo_2$ and that the effect of BMI was largely mediated by atelectasis since the effect of BMI on $Spo_2$ was nearly completely attenuated when adjusting for atelectasis. In the subset of participants with $Spo_2$ <96% where the relationships were close to linear, the proportion of the effect mediated by atelectasis was 81.5% (95% CI, 56.0–100).

Showing that atelectasis in the supine position can explain $Spo_2$ in the seated position challenges the notion that atelectasis in lung-dependent regions are merely postural with often little clinical relevance,[35] or artifacts expected to solve by performing chest CT in the prone position.[36] Furthermore, the presence of atelectasis with consequences in $Spo_2$ of obese patients before elective surgery strengthens our understanding of the pathophysiology of obesity, possibly implying that chronic hypoxemia in patients with obesity could be largely explained by mechanisms leading to atelectasis[37] and potentially related to development of chronic dyspnea,[38] intolerance to exercise,[39] or pulmonary hypertension through hypoxic vasoconstriction.[40]

The prediction plots showed that only the curves for $Spo_2$ values between 89% and 96% are well represented. While it would not be possible to extend the *y*-axis to values <0% to predict $Spo_2$ >96%, it would be possible to extend the *y*-axis to higher atelectasis percentage values, meaning that $Spo_2$ values <88% could likely be predicted. We found these results encouraging since they show that predicting preoperative atelectasis without the need of performing a chest CT is possible and could be attempted in future studies. As this is a proof-of-concept, we advise against immediate implementation and we instead encourage researchers to develop and validate a prediction model of atelectasis percentage coverage on large-scale, sufficiently powered, and representative studies.[41] Prediction models of preoperative atelectasis could be used to plan and guide optimal intraoperative ventilation parameters since individualized ventilation strategies have shown to be promising for preventing postoperative atelectasis,[42] while also allowing to estimate the extent to which postoperative atelectasis are clinically relevant with respect to atelectasis that were already present before surgery.

Strengths of our study include the large sample of patients with obesity, including extreme BMI and the availability of chest CT scans before surgery due to the COVID-19 pandemic, which allowed us to study preoperative atelectasis. Furthermore, we implemented DAG-informed modeling which is currently the recommended approach to study potentially causal relationships.[43]

Limitations of our study include that atelectasis percentage was rounded to the lowest 2.5% category, which caused loss of information. This could have led to an underestimation of the prevalence of atelectasis. Additionally, we did not have good documentation in medical records of other potential confounders like recent respiratory infections or heart disease. Although COVID-19 could be an additional potential confounder, we excluded participants with a prior history of COVID-19 or suggestive SARS-CoV-2 infection according to CO-RADS.

One additional limitation is that our study is poorly representative of men since 90.7% were female, although this is a common situation in studies conducted in bariatric surgery (70%–79% female).[8,15,44,45] Furthermore, our sample was overall younger than other large representative studies which could explain why the prevalence of comorbidities like hypertension and diabetes were lower.[45] Since this study captured participants in the context of medical tourism, generalizability to other populations could be restricted. Additionally, this was a cross-sectional observational study with retrospective assessment of medical images, reason why the ability to make causal inferences could be limited. The possibility of selection bias for the main analysis may be low since our study captured 84% of participants originally scheduled for surgery. Nonetheless, it is a latent possibility that participants not presenting to surgery could have done so due to factors related to exposure and outcome, or colliders, which could have induced selection bias. Caution is warranted for the calculation of the proportion mediated, as having selected on a collider ($Spo_2$ <96%) could have induced bias. This estimate should be read as an approximation and interpreted in conjunction with the complete-case analysis (Figure 2) for which estimation of the proportion mediated was not possible due to nonlinearity of the relationship between BMI and $Spo_2$. Since our study was restricted to the preoperative period, future longitudinal studies could aim to investigate the impact of preoperative atelectasis on postoperative outcomes.

## CONCLUSIONS

The overall prevalence of preoperative atelectasis in patients with obesity undergoing bariatric surgery was 32.63% (95% CI, 26.97–38.85) and increased with higher obesity categories. The mean atelectasis percentage coverage in chest CT was 2.66% (95% CI, 2.07–3.26) and similarly increased with higher BMI. The risk of having a greater prevalence and extension of atelectasis were significantly higher at BMI ≥45 kg/m$^2$. Preoperative atelectasis mediated the effect of BMI on preoperative $Spo_2$, with atelectasis alone explaining 70% of the variability in $Spo_2$.

### DISCLOSURES

**Conflicts of Interest:** None. **Funding:** None. **This manuscript was handled by:** Tong J. Gan, MD, MHS, FRCA.

### REFERENCES

1. National Center for Health Statistics. Prevalence of obesity in the U.S. Population, 2017-2018. NHANES Interactive Data Visualizations 2023. Accessed November 28, 2023. https://www.cdc.gov/nchs/nhanes/visualization/index.htm.
2. Statistics Canada. Health characteristics, annual estimates 2022. Canadian Community Health Survey—Annual Component 2023:Table 13-10-0096-01. Accessed November 28, 2023. https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=1310009601.
3. Campos-Nonato I, Galván-Valencia O, Hernández-Barrera L, Oviedo-Solís C, Barquera S. Prevalencia de obesidad y factores de riesgo asociados en adultos mexicanos: resultados de la Ensanut 2022. *Salud Públ México*. 2023;65:s238–s247.
4. Pépin JL, Timsit JF, Tamisier R, Borel JC, Lévy P, Jaber S. Prevention and care of respiratory failure in obese patients. *Lancet Resp Med*. 2016;4:407–418.
5. Schetz M, Jong AD, Deane AM, et al. Obesity in the critically ill: a narrative review. *Intensive Care Med*. 2019;45:757–769.
6. Regli A, Ungern-Sternberg BS von, Reber A, Schneider MC. Impact of spinal anaesthesia on peri-operative lung volumes in obese and morbidly obese female patients. *Anaesthesia*. 2006;61:215–221.
7. Hedenstierna G, Rothen HU. Respiratory function during anesthesia: effects on gas exchange. *Compr Physiol*. 2012;2:69–96.
8. Eichenberger A-S, Proietti S, Wicky S, et al. Morbid obesity and postoperative pulmonary atelectasis: an underestimated problem. *Anesth Analg*. 2002;95:1788–1792.
9. Lagier D, Zeng C, Fernandez-Bustamante A, Vidal Melo MF. Perioperative pulmonary atelectasis: Part II. Clinical implications. *Anesthesiology*. 2022;136:206–236.

10. Inselman LS, Chander A, Spitzer AR. Diminished lung compliance and elevated surfactant lipids and proteins in nutritionally obese young rats. *Lung*. 2004;182:101–117.
11. Schipke J, Jütte D, Brandenberger C, et al. Dietary carbohydrates and fat induce distinct surfactant alterations in mice. *Am J Respir Cell Mol Biol*. 2021;64:379–390.
12. Lugogo N, Francisco D, Addison KJ, et al. Obese asthmatic patients have decreased surfactant protein A levels: mechanisms and implications. *J Allergy Clin Immunol*. 2018;141:918–926.e3.
13. Zeng C, Lagier D, Lee J-W, Vidal Melo MF. Perioperative pulmonary atelectasis: Part I. Biology and mechanisms. *Anesthesiology*. 2022;136:181–205.
14. Ruze R, Li J, Xu Q, et al. Sleeve gastrectomy ameliorates alveolar structures and surfactant protein expression in lungs of obese and diabetic rats. *Int J Obes (Lond)*. 2020;44:2394–2404.
15. Reinius H, Jonsson L, Gustafsson S, et al. Prevention of atelectasis in morbidly obese patients during general anesthesia and paralysis. *Anesthesiology*. 2009;111:979–987.
16. Prokop M, Everdingen W van, Rees Vellinga T van, et al. CO-RADS: A categorical CT assessment scheme for patients suspected of having COVID-19—definition and evaluation. *Radiology*. 2020;296:E97–104.
17. World Health Organization. A healthy lifestyle—WHO recommendations. Fact sheets 2010. Accessed November 20, 2023. https://www.who.int/europe/news-room/fact-sheets/item/a-healthy-lifestyle---who-recommendations.
18. Magnusson L, Spahn DR. New concepts of atelectasis during general anaesthesia. *Br J Anaesth*. 2003;91:61–72.
19. Östberg E, Thorisson A, Enlund M, Zetterström H, Hedenstierna G, Edmark L. Positive end-expiratory pressure and postoperative atelectasis. *Anesthesiology*. 2019;131:809–817.
20. Textor J, Zander B van der, Gilthorpe MS, Liśkiewicz M, Ellison GT. Robust causal inference using directed acyclic graphs: the R package "dagitty." *Int J Epidemiol*. 2017;45:dyw341.
21. Ankan A, Wortel IMN, Textor J. Testing graphical causal models using the R package "dagitty." *Current Protocols*. 2021;1:1–22.
22. Crocker ME, Hossen S, Goodman D, et al; HAPIN Investigators. Effects of high altitude on respiratory rate and oxygen saturation reference values in healthy infants and children younger than 2 years in four countries: a cross-sectional study. *Lancet Global Health*. 2020;8:e362–e373.
23. Mancilla-Galindo J, Guerrero-Gutiérrez MA, Ramírez-Mata LC, Mendez-Díaz A. Replication data for: Preoperative atelectasis in patients with obesity undergoing bariatric surgery a cross-sectional study. Accessed May 27, 2024. https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/4JZZLB.
24. Yorlets RR, Lee Y, Gantenberg JR. Calculating risk and prevalence ratios and differences in R: developing intuition with a hands-on tutorial and code. *Ann Epidemiol*. 2023;86:104–109.
25. VanderWeele TJ, Ding P. Sensitivity analysis in observational research: introducing the E-value. *Ann Intern Med*. 2017;167:268–274.
26. Harrell FE. Ordinal logistic regression. In: Harrell FE, ed. *Regression Modeling Strategies*. 2nd ed. *Springer Series in Statistics*. Springer, 2015:311–25.
27. Harrell FE. Assessing the proportional odds assumption and its impact. Statistical thinking 2022. Accessed November 26, 2023. https://www.fharrell.com/post/impactpo.
28. Mancilla-Galindo J. Preoperative atelectasis in bariatric surgery. Accessed May 27, 2024. https://github.com/javimangal/preoperative-atelectasis.
29. Yee TW. *Vector Generalized Linear and Additive Models*. Springer; 2015.
30. Huber M. Identifying causal mechanisms (primarily) based on inverse probability weighting. *J Appl Econometrics*. 2014;29:920–943.
31. Schumann R, Shikora SA, Sigl JC, Kelley SD. Association of metabolic syndrome and surgical factors with pulmonary adverse events, and longitudinal mortality in bariatric surgery. *Br J Anaesth*. 2015;114:83–90.
32. Bluth T, Serpa Neto A, Schultz MJ, et al; Writing Committee for the PROBESE Collaborative Group of the PROtective VEntilation Network (PROVEnet) for the Clinical Trial Network of the European Society of Anaesthesiology. Effect of intraoperative high positive end-expiratory pressure (PEEP) with recruitment maneuvers vs low PEEP on postoperative pulmonary complications in obese patients. *JAMA*. 2019;321:2292–2305.
33. Steier J, Lunt A, Hart N, Polkey MI, Moxham J. Observational study of the effect of obesity on lung volumes. *Thorax*. 2014;69:752–759.
34. Li X, Liu H, Wang J, et al. Individualized positive end-expiratory pressure on postoperative atelectasis in patients with obesity: a randomized controlled clinical trial. *Anesthesiology*. 2023;139:262–273.
35. Kotloff RM. Acute respiratory failure in the surgical patient. In: Grippi MA, Antin-Ozerkis DE, Dela Cruz CS, Kotloff RM, Kotton CN, Pack AI, eds. *Fishman's Pulmonary Diseases and Disorders*. 6th ed. McGraw-Hill Education, 2023;1801–1815.
36. Primack SL, Remy-Jardin M, Remy J, Müller NL. High-resolution CT of the lung: pitfalls in the diagnosis of infiltrative lung disease. *AJR Am J Roentgenol*. 1996;167:413–418.
37. Bhatawadekar SA, Peters U, Walsh RR, et al. Air trapping versus atelectasis in obesity: relationship to late-onset nonallergic asthma and aging. *Ann Am Thoracic Soc*. 2022;19:135–139.
38. Hagenburg J, Bertin E, Salmon J-H, et al. Association between obesity-related dyspnea in daily living, lung function and body composition analyzed by DXA: a prospective study of 130 patients. *BMC Pulm Med*. 2022;22:103.
39. Lewis MT, Lujan HL, Tonson A, Wiseman RW, DiCarlo SE. Obesity and inactivity, not hyperglycemia, cause exercise intolerance in individuals with type 2 diabetes: solving the obesity and inactivity versus hyperglycemia causality dilemma. *Med Hypotheses*. 2019;123:110–114.
40. Antoine MH, Sankari A, Bollu PC. Obesity-hypoventilation syndrome. 2024. Accessed May 27, 2024. https://www.ncbi.nlm.nih.gov/books/NBK482300/
41. Royen FS van, Moons KGM, Geersing G-J, Smeden M van. Developing, validating, updating and judging the impact of prognostic models for respiratory diseases. *Eur Respir J*. 2022;60:2200250.
42. Boesing C, Schaefer L, Hammel M, et al. Individualized positive end-expiratory pressure titration strategies in superobese patients undergoing laparoscopic surgery: prospective and nonrandomized crossover study. *Anesthesiology*. 2023;139:249–261.
43. Lederer DJ, Bell SC, Branson RD, et al. Control of confounding and reporting of results in causal inference studies. *Ann Am Thoracic Soc*. 2019;16:22–28.
44. Baltieri L, Peixoto-Souza FS, Rasera-Junior I, Montebelo MI de L, Costa D, Pazzianotto-Forti EM. Analysis of the prevalence of atelectasis in patients undergoing bariatric surgery. *Braz J Anesthesiol*. 2016;66:577–582.
45. DeMaria EJ, Pate V, Warthen M, Winegar DA. Baseline data from American society for metabolic and bariatric surgery-designated bariatric surgery centers of excellence using the bariatric outcomes longitudinal database. *Surg Obes Relat Dis*. 2010;6:347–355.