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ORIGINAL ARTICLE

Characterizing the spectrum of body mass index associated with severe postoperative pulmonary complications in children

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Abstract

Purpose While high body mass index (BMI) is a recognized risk factor for pulmonary complications in adults, its importance as a risk factor for complications following pediatric surgery is poorly described. We evaluated the association between BMI and severe pediatric perioperative pulmonary complications (PPCs).

Methods In this retrospective cohort study, we evaluated pediatric patients (aged 2–17 years) undergoing elective procedures in the 2015 Pediatric National Surgical Quality Improvement Program (NSQIP-P). Severe PPCs were defined as either pneumonia/reintubation within 3 days of surgery, or pneumonia/reintubation as an index complication within 7 days. Univariate and multivariable logistic regression analyses adjusting for patient factors and surgical case-mix tested associations between BMI class—using the Centers for Disease Control age- and sex-dependent BMI percentiles—and severe PPCs.

Results Among 40,949 patients, BMI class was distributed as follows: 2740 (6.7%) were underweight, 23,630 (57.7%) normal weight, 6161 (15.0%) overweight, and 8418 (20.6%) obese. Overweight BMI class was not associated with PPCs in univariate analyses, but became statistically significant after adjustment [OR 1.84 (95% CI 1.07–3.15), $p = 0.03$], and persisted across multiple adjustment approaches. Neither underweight [OR 1.01 (95% CI 0.53–1.94), $p = 0.97$] nor obesity [OR 1.10 (95% CI 0.63–1.94), $p = 0.73$] were associated with PPCs after adjustment.

Conclusion Overweight pediatric patients have an elevated, previously underappreciated risk of severe PPCs. Contrary to prior studies, the present study found no greater risk in obese children, perhaps due to bias, confounding, or practice migration from "availability bias". Findings from the present study, taken with prior work describing pulmonary risks of obesity, suggest that both obese and overweight children may be evaluated for tailored perioperative care to improve outcomes.

Keywords Pediatric surgery · BMI · Respiratory complications

Introduction

Elevated body mass index (BMI) is an important global health challenge among both adults and children [1–4]. The Centers for Disease Control and Prevention (CDC) defines pediatric obesity as BMI ≥ 95th percentile for a child's age and sex, and extreme obesity as BMI ≥ 120% of the 95th percentile; rates of pediatric obesity have nearly doubled in the past 20 years from 11% to nearly 20% currently [4]. Rates of extreme obesity among children aged 12–19 years have increased more than threefold during the same time from nearly 3 to 9% [4]. The association between BMI class and perioperative pulmonary complications (PPCs) has been well documented in adult surgical patients [5], in part due to the association between elevated BMI and sleep apnea [6–9]. Moreover, these pulmonary complications are shown to be both morbid and costly [10, 11]. Recent

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work has investigated potential risk factors for pulmonary complications among various narrow pediatric subsets (predominantly emergency surgery and otolaryngology), aiming to improve identification of high-risk patients for targeted preventive interventions. Although numerous studies have explored potential associations between obesity and PPCs in pediatric surgical patients [12–15], the literature lacks detailed epidemiologic characterization of risks for "overweight" children undergoing diverse surgical procedures, in both the immediate and extended perioperative period [16–19].

We used data from the American College of Surgeons, Pediatric National Surgical Quality Improvement Project (NSQIP-P) [20, 21] to evaluate the extent to which BMI class is a risk factor for early, severe PPCs amongst a broad group of pediatric patients undergoing elective surgical procedures with a diverse case mix. This work focused on pneumonia or reintubation with in the first 3 postoperative days or when occurring as a first, or index complication, within 7 days postoperatively, to pinpoint primary respiratory events associated with overweight or obese BMI class in pediatric patients.

Materials and methods

Study design

In this retrospective cohort study, we evaluated all eligible patients contained within the 2015 American College of Surgeons, Pediatric National Surgical Quality Improvement Project (NSQIP-P) Participant Use Data File (PUF) [20] to evaluate the impact of BMI on perioperative pulmonary complications. This study utilized de-identified data and was determined to be exempt from review by the Mayo Clinic Institutional Review Board. The requirement for written informed consent was waived. The conduct and reporting of results herein follows the strengthening the reporting of observational studies in epidemiology guidelines [22].

Patient sample

All elective pediatric surgical patients (aged 2–17 years) were identified from the NSQIP-P 2015 PUF [20]. Of those available, patients were excluded if they were undergoing emergency surgery (due to our desire to study elective pediatric surgical practice risk profiles). Patients aged < 2 years were not selected as CDC weight class definitions only apply to children age ≥ 2 [23]. Additional exclusions were made to account for those in whom the primary outcome (pneumonia or reintubation) was either pre-existing or not possible: required pre-operative ventilation, oxygen supplementation, or inotropic support, had a pre-existing tracheostomy, preoperative evidence of pneumonia, SIRS, sepsis or septic shock. Finally, patients were excluded if they received an ASA 5 classification, or had missing covariates necessary to determine the primary aims of this study, BMI or relative value unit (RVU) (Fig. 1). Potential patient-factor confounders of any association between early PPC and BMI class were prioritized based on review of the literature including published risk adjustment models in the NSQIP-P semiannual report as well as clinical experience. Variables extracted from the NSQIP-P 2015 PUF for use in multivariable model adjustments, included: height, weight, age, sex, American Society of Anesthesiologists Physical Status (ASA), race/ethnicity, history of asthma, bronchopulmonary dysplasia/chronic lung disease, structural pulmonary/airway disease, hematologic disorders, cardiac risk factors, neuromuscular disorders, structural central nervous system abnormality, cerebral palsy, developmental delay, and seizure disorder. These data benefit from being a large-scale, rigorously standardized, multi-institutional patient cohort, covering all major surgical specialties. With an audited disagreement rate of around 2%, NSQIP-P is one of the most robust datasets available, with complete outcome data available up to 30 days postoperatively [20].

Definition of BMI class

Height, weight, age and sex data were extracted from the 2015 NSQIP-P PUF. Using these data points, BMI was categorized using the CDC algorithm for age- and sex-adjusted BMI percentile score [24] as follows: underweight (< 5th%), normal (5 to < 85%), overweight (85 to < 95%) and obese (≥ 95%) [24]. These standardized BMI percentiles were developed, and express BMI in relation to historically surveyed children in the United States. BMI percentile was chosen as a surrogate measure of fatness as it is felt to most accurately reflect the height, weight and body fat changes

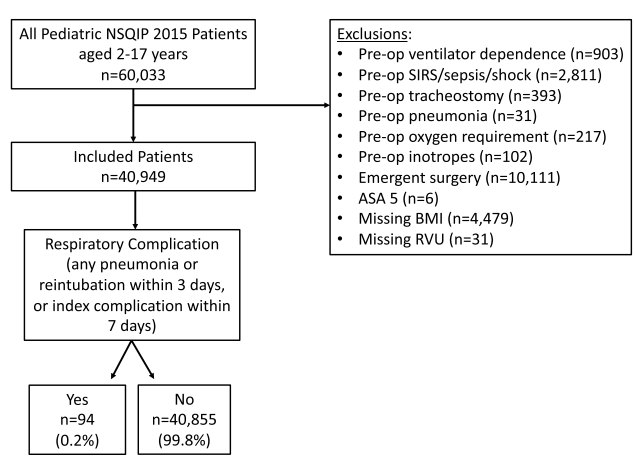

Fig. 1 Patient flow diagram

seen during childhood development in relation to societal norms. As above, patients with missing variables necessary to calculate BMI percentile were excluded from analyses; therefore, BMI data were complete for all study participants.

Definition of severe perioperative pulmonary complication

Definitions of early severe PPCs were based on literature review and clinical experience [11, 16, 25]. The primary outcome "perioperative pulmonary complications" was intended to be a pragmatic composite outcome reflecting severe postoperative respiratory events, and was defined as any intubation, pneumonia, or both occurring in the first 3 days postoperatively, or an index intubation or index pneumonia (or both) occurring within 7 days postoperatively. An index complication must be the first postoperative complication not preceded by other complications. In an effort to ensure reintubation events were representative of a primary *pulmonary* complication, potential disqualifiers for "index complications" included wound infection, pulmonary embolism, bleeding, urinary tract infection, venous thromboembolism, acute renal insufficiency or acute renal failure, sepsis, shock, cardiac arrest, coma > 24 h, stroke, seizure, nerve injury, graft/prosthesis/flap failure, central line-associated blood stream infection, *Clostridium difficile* colitis, or readmission. The first qualifying diagnosis—pneumonia, intubation, or both—were displayed graphically by postoperative day. Sensitivity analyses were conducted evaluating the relationship between BMI class and any pneumonia or reintubation within 7 days of surgery. Definition standards for all complications, including pneumonia (NSQIP-P variable #237) and reintubation (NSQIP-P variable #240), were described by NSQIP-P which uses trained abstractors and clinical chart review to assess for incident complications [20].

Statistical analysis

Baseline characteristics were summarized using frequency and percentage, or median and interquartile range if non-normally distributed, and compared between BMI classes using the Chi-square or Kruskal–Wallis test for categorical and continuous data points, respectively. Univariate logistic regression analysis was conducted evaluating the relationship between BMI class and PPCs. Multivariable logistic regression further evaluated the risk of PPCs by BMI class after adjusting for potential confounders. Variables with presumed clinical significance—age, sex, history of asthma, ASA, race/ethnicity, bronchopulmonary dysplasia/chronic lung disease, and structural pulmonary/airway abnormality—were included in multivariable logistic regression models as potential confounders. Sex, history of asthma, bronchopulmonary dysplasia/chronic lung disease and structural pulmonary/airway abnormality were removed as they failed to achieve statistical significance upon multivariable modeling. Remaining covariates (hematologic disorders, cardiac risk factors, neuromuscular disorders, structural central nervous system abnormality, cerebral palsy, developmental delay, previous cardiac surgery, nutritional support and seizure disorder) with statistically significant associations with PPCs in univariate models were evaluated as potential confounders to the relationship between BMI and PCCs. To avoid overfitting the final model, given the small number of complications, covariates were removed if they did not alter the association between BMI and PPC by 10% change in the beta coefficient, or were not statistically significantly associated with PPCs. Results of univariate and multivariable models are reported as odds ratio (OR) and 95% CI.

An a priori plan to extensively control for potential surgical-factor confounders (surgical case-mix) in this diverse population was addressed using multiple variable forms. First, we investigated work RVU—a measure of value, and part of the resource-based relative value scale used by Medicare for physician services reimbursement. Work RVU was based on all Current Procedural Terminology (CPT®) procedures coded, in both linear and squared (after centering) forms. Thereafter, we investigated case-mix definitions based on primary surgical site and primary organ system as follows: abdominal, respiratory (inclusive of oral cavity to lower airways and lungs), nervous system (defined as intracranial and intradural procedures but not inclusive of nervous system procedures such as peripheral nerve surgery or vagotomy), other head and neck (not inclusive of respiratory, intracranial or intradural procedures), skin and extremity, spine (exclusive of intradural procedures), and thoracic (minus respiratory procedures). Of note, neither cardiac nor transplant surgical procedures are included in NSQIP-P. Sensitivity analysis, evaluating the relationship between BMI class and any pneumonia or reintubation occurring within 7 days of surgery was conducted, utilizing identical multivariable models.

Given the central aim to determine the magnitude of effect between BMI and PPCs in a heterogenous group of pediatric patients presenting for elective surgery, the sample size for this study was based upon complete enumeration of eligible and consecutive individuals within NSQIP-P for 2015. Though an a priori power calculation was not performed, our study population consisted of an entire calendar year's volume of patients from over 80 institutions across the United States and is sufficient to identify a clinically meaningful effect size.

Results

Of 84,056 patients available in the NSQIP-P 2015 PUF, 60,033 patients aged 2–17 years were selected. Exclusions were made as follows: emergency surgery ($n=10{,}111$), pre-operative ventilation ($n=903$), oxygen supplementation ($n=217$), inotropic support ($n=102$), pre-existing tracheostomy ($n=393$), preoperative evidence of pneumonia ($n=31$), or SIRS, sepsis or septic shock ($n=2811$), ASA 5 classification ($n=6$), missing BMI ($n=4479$), missing RVU ($n=31$) (Fig. 1). After exclusion criteria were applied, a total of 40,949 patients were available for inclusion. From this cohort, 2740 children (6.7%) were considered underweight, 23,630 (57.7%) were considered normal weight, 6161 (15.0%) were overweight, and 8418 (20.6%) were obese. Data relating to the primary outcome, index postoperative pulmonary complications, were available for all participants, and occurred in 94 (0.2%) of patients. Incidence by BMI category is as follows: 12/2740 (0.4%) for underweight patients, 46/23,630 (0.2%) for normal weight, 19/6161 (0.3%) for overweight, and 17/8418 (0.2%) for obese children. Sensitivity analysis considering any pneumonia or reintubation within 7 days yielded 108 (0.3%) patients. Evaluation of the timing of respiratory complications in this cohort (Fig. 2) reveals that 76 of the 94 PPCs (80.9%) occurred between the day of surgery and postoperative day 3. Fifty-eight of these (76.3%) occurred after the day of surgery. Pneumonia was the most common PPC, occurring as the first respiratory complication in 59 of the 94 (62.8%) patients, and peaking on postoperative day 2 ($n=23$, 39.0%) and 3 ($n=12$, 20.3%). The first qualifying PPC was reintubation for 26 (27.7%) patients, with the majority ($n=12$, 46.2%) occurring on the day of surgery. Nine patients (9.6%) experienced pneumonia and reintubation on the same postoperative day.

Patient factors and surgical case mix varied across BMI groups (Table 1). Obese patients were more likely to be undergoing skin or extremity surgery, and less likely to be undergoing respiratory or thoracic surgery. Obese patients had the highest incidence of asthma, whereas underweight patients were more likely to have bronchopulmonary dysplasia/chronic lung disease and structural airway abnormalities. Neuromuscular disorders, cerebral palsy, structural CNS abnormalities, developmental delay, seizure disorders, a history of prior cardiac surgery and need for nutritional support were all more prevalent in the underweight group. Findings from univariate analysis evaluating the association between BMI group and postoperative pulmonary complication are shown as Electronic Supplementary Material 1.

Associations between BMI and PPCs were tested across a series of multivariable models (Table 2) that adjusted for patient factors (model 1), patient factors and surgical variables using of work RVU (model 2), and patient factors and surgical variables using anatomic and organ system-based case-mix designation (model 3). In all 3 models, the odds of

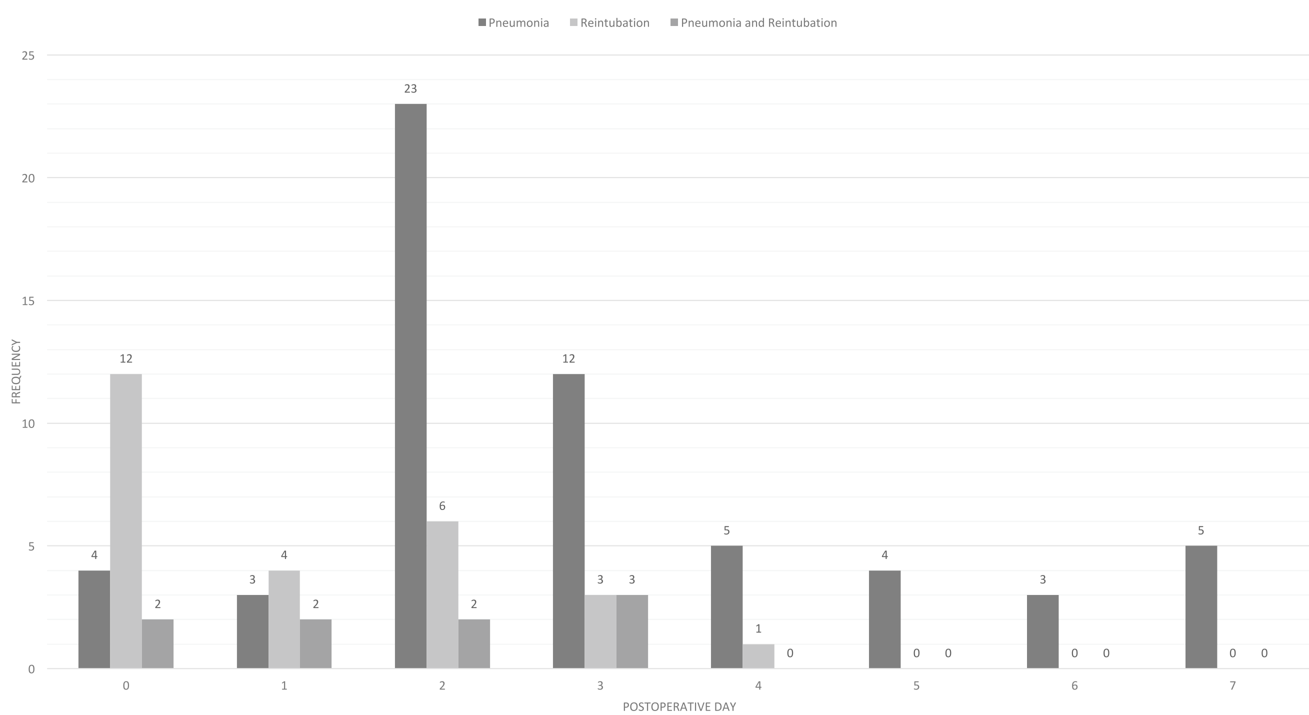

Fig. 2 Timing and type of respiratory complications by postoperative day

Table 1 Patient characteristics by body mass index group

Characteristic	All pts	BMI percentile				p value
	n = 40,949	< 5th (n = 2740)	5th to < 85th (n = 23,630)	85th to < 95th (n = 6161)	≥ 95th (n = 8418)	
Total RVU, median (IQR)	13.16 (9.05, 24.22)	15.5 (9.45, 26.71)	13.71 (8.73, 24.90)	12.92 (9.13, 23.95)	12.92 (9.45, 22.29)	< 0.001
Case mix						< 0.001
Abdominal	12,158 (29.7)	995 (36.3)	6980 (29.5)	1746 (28.3)	2437 (28.9)	
Respiratory (including oral/soft tissue)	3103 (7.6)	185 (6.8)	2022 (8.6)	440 (7.1)	456 (5.4)	
Nervous system (intracranial/intradural)	1869 (4.6)	102 (3.7)	1048 (4.4)	306 (5.0)	413 (4.9)	
Other head and neck	7050 (17.2)	377 (13.8)	4142 (17.5)	1116 (18.1)	1415 (16.8)	
Skin or extremity	10,453 (25.5)	543 (19.8)	5450 (23.1)	1720 (27.9)	2740 (32.5)	
Spine (non-intradural)	5103 (12.5)	430 (15.7)	3120 (13.2)	717 (11.6)	836 (9.9)	
Thoracic (non-respiratory)	1213 (3.0)	108 (3.9)	868 (3.7)	116 (1.9)	121 (1.4)	
Male sex	21,071 (51.5)	1636 (59.7)	12,203 (51.6)	2957 (48.0)	4275 (50.8)	< 0.001
Age—years, median (IQR)	10 (5.14)	9 (4.14)	9 (5.14)	10 (6.14)	11 (7.14)	< 0.001
Race/ethnicity						< 0.001
Non-Hispanic White	24,898 (60.8)	1719 (62.7)	15,026 (63.6)	3685 (59.8)	4468 (53.1)	
Hispanic White	4271 (10.4)	216 (7.9)	2131 (9.0)	722 (11.7)	1202 (14.3)	
Black or African American	5454 (13.3)	374 (13.6)	2835 (12.0)	796 (12.9)	1449 (17.2)	
Other	6326 (15.4)	431 (15.7)	3638 (15.4)	958 (15.5)	1299 (15.4)	
ASA class						< 0.001
1-No disturb	11,522 (28.2)	501 (18.3)	7317 (31.0)	1940 (31.5)	1764 (21.0)	
2-Mild disturb	20,091 (49.1)	1099 (40.2)	11,214 (47.5)	3004 (48.8)	4774 (56.8)	
3-Severe disturb	9003 (22.0)	1084 (39.6)	4909 (20.8)	1189 (19.3)	1821 (21.7)	
4-Life threat	272 (0.7)	52 (1.9)	154 (0.7)	20 (0.3)	46 (0.5)	
History of asthma	3506 (8.6)	263 (9.6)	1896 (8.0)	528 (8.6)	819 (9.7)	< 0.001
Bronchopulmonary dysplasia/chronic lung disease	904 (2.2)	136 (5.0)	562 (2.4)	103 (1.7)	103 (1.2)	< 0.001
Structural pulmonary/airway abnormality	1892 (4.6)	184 (6.7)	1103 (4.7)	259 (4.2)	346 (4.1)	< 0.001
Hematologic disorder	1146 (2.8)	98 (3.6)	724 (3.1)	152 (2.5)	172 (2.0)	< 0.001
Cardiac risk factors						< 0.001
No cardiac risk factors	38,393 (93.8)	2442 (89.1)	22,065 (93.4)	5840 (94.8)	8046 (95.6)	
Minor cardiac risk factors	1500 (3.7)	178 (6.5)	886 (3.7)	191 (3.1)	245 (2.9)	
Major cardiac risk factors	917 (2.2)	108 (3.9)	579 (2.5)	115 (1.9)	115 (1.4)	
Severe cardiac risk factors	139 (0.3)	12 (0.4)	100 (0.4)	15 (0.2)	12 (0.1)	
Neuromuscular disorder	2451 (6.0)	398 (14.5)	1293 (5.5)	331 (5.4)	429 (5.1)	< 0.001
Structural CNS abnormality	5225 (12.8)	554 (20.2)	2793 (11.8)	794 (12.9)	1084 (12.9)	< 0.001
Cerebral palsy	2245 (5.5)	523 (19.1)	1215 (5.1)	242 (3.9)	265 (3.1)	< 0.001

Table 1 (continued)

Characteristic	All pts	BMI percentile				p value
	n = 40,949	< 5th (n = 2740)	5th to < 85th (n = 23,630)	85th to < 95th (n = 6161)	≥ 95th (n = 8418)	
Developmental delay/impaired cognitive status	7060 (17.2)	1004 (36.6)	3910 (16.5)	910 (14.8)	1236 (14.7)	< 0.001
Seizure disorder	2903 (7.1)	480 (17.5)	1517 (6.4)	384 (6.2)	522 (6.2)	< 0.001
Previous cardiac surgery	1208 (3.0)	156 (5.7)	752 (3.2)	139 (2.3)	161 (1.9)	< 0.001
Nutritional support	1496 (3.7)	307 (11.2)	865 (3.7)	170 (2.8)	154 (1.8)	< 0.001

Pts patients, *BMI* body mass index, *RVU* relative value units, *IQR* interquartile range, *ASA* American Society of Anesthesiologists, *CNS* central nervous system

All values *n* (percentage) unless reported otherwise. *p* value calculated using Chi-square test for categorical data and Kruskal–Wallis for continuous data

Table 2 Multivariable logistic regression analysis evaluating association between BMI group and postoperative pulmonary complications

Variable	Model 1		Model 2		Model 3	
	OR (95% CI)	p value	OR (95% CI)	p value	OR (95% CI)	p value
BMI percentile		0.16		0.15		0.13
< 5th	1.01 (0.53–1.94)	0.97	1.04 (0.54–2.00)	0.90	0.99 (0.51–1.90)	0.97
5th to < 85th	–	–	–	–	–	–
85th to < 95th	1.84 (1.07–3.15)	0.03	1.87 (1.09–3.22)	0.02	1.90 (1.11–3.28)	0.02
≥ 95th	1.10 (0.63–1.94)	0.73	1.20 (0.68–2.11)	0.53	1.20 (0.68–2.12)	0.53
Patient factors						
Age	1.00 (0.96–1.05)	1.00	0.99 (0.94–1.03)	0.56	1.00 (0.96–1.04)	0.95
Race/ethnicity (black/AA vs. other)	1.68 (1.03–2.73)	0.04	1.70 (1.05–2.76)	0.03	1.67 (1.03–2.71)	0.04
ASA class		< 0.001		< 0.001		< 0.001
ASA 1	–	–	–	–	–	–
ASA 2	6.41 (1.52–27.11)	0.01	5.23 (1.23–22.19)	0.03	5.40 (1.27–22.97)	0.02
ASA 3	19.49 (4.65–81.72)	< 0.001	14.28 (3.39–60.21)	< 0.001	15.46 (3.64–65.55)	< 0.001
ASA 4	54.52 (10.52–282.50)	< 0.001	37.16 (7.10–194.41)	< 0.001	38.85 (7.35–205.28)	< 0.001
Neuromuscular disorder	2.03 (1.23–3.34)	0.005	1.66 (1.00–2.77)	0.05	1.96 (1.16–3.34)	0.01
Seizure disorder	2.01 (1.22–3.29)	0.006	2.05 (1.25–3.38)	0.005	2.23 (1.34–3.73)	0.002
Nutritional support	3.25 (1.93–5.47)	< 0.001	3.16 (1.86–5.35)	< 0.001	3.09 (1.80–5.29)	< 0.001
Total RVU			1.03 (1.02–1.05)	< 0.001		
Centered-squared total RVU			1.00 (1.00–1.00)	0.03		
Case mix						0.048
Abdominal surgery					–	–
Respiratory					1.21 (0.56–2.64)	0.63
Nervous system					1.03 (0.49–2.17)	0.94
Other head/neck					0.27 (0.11–0.70)	0.007
Skin or extremity					0.48 (0.23–0.98)	0.04
Spine					1.06 (0.61–1.87)	0.83
Thoracic					1.06 (0.25–4.46)	0.94

Model 1 adjusting for patient factors, *Model 2* adjusting for patient factors and RVU, *Model 3* adjusting for patient factors and case mix, *OR* odds ratio, *CI* confidence interval, *BMI* body mass index, *ASA* American Society of Anesthesiologists Physical Status Classification, *AA* African American, *RVU* relative value units

PPC were significantly greater in the overweight group compared to normal weight [model 1 OR 1.84 (CI 1.07–3.15), $p = 0.03$; model 2 OR 1.87 (CI 1.09–3.22), $p = 0.02$; model 3 OR 1.90 (CI 1.11–3.28), $p = 0.02$]. Neither underweight status nor obese status was associated with PPCs after adjustment. When considering type of surgery, children undergoing head and neck [(OR 0.27, CI 0.11–0.70) $p = 0.007$] or skin and extremity [(OR 0.48, CI 0.23–0.98) $p = 0.04$] surgery were statistically less likely to experience PPCs compared with those undergoing abdominal surgery. Similarly, odds of PPCs increased with increasing RVU [(OR 1.03 per 1 unit increase in RVU, CI 1.02–1.05) $p < 0.001$]. Sensitivity analyses considering any pneumonia or reintubation within 7 days, as a secondary outcome variable, yielded similar findings (Electronic Supplementary Material 2).

Discussion

In this large retrospective cohort study of surgically diverse elective pediatric patients, overweight BMI (85th to < 95th BMI percentile) was associated with greater odds of postoperative pulmonary complications defined as early or index complications within the first 7 days after surgery. This excess risk of severe PPCs in this large and generalizable population of overweight children persisted after extensive adjustment for patient comorbidities and surgical case-mix. These findings highlight overweight pediatric patients as a previously unrecognized high-risk group for severe early postoperative pulmonary complications. The overweight pediatric population may benefit from future investigations designed to study tailored perioperative care, including choice of anesthetic techniques, opioid administration, planned admissions or level of monitoring for risk mitigation. Such studies may inform perioperative risk counselling in this vulnerable group.

The present study extends findings from prior work—predominantly focusing on extremes of obesity—by suggesting that at-risk patients include the very commonly encountered group of "overweight" children, as well as describing this risk across a broad range of procedural categories and defining the timing of risk. Other recent work has demonstrated that high BMI was associated with a greater 30-day risk of pulmonary complications in pediatric patients, however this work was restricted to trauma and emergency gastrointestinal procedures [17, 18]. The majority of pediatric surgery is elective, and the present study of children presenting for diverse surgical procedures demonstrates the broad importance of PPC risk in overweight children—including those coming for elective surgeries that might otherwise be considered low risk. In addition, prior work did not differentiate between index versus secondary pulmonary complications, resulting from a cascade of events following other perioperative complications [17, 18]. As a result, it was unclear whether pulmonary complications occurred as a primary event or, for example, secondary to sepsis or surgical site infections for which obese children may have greater risk. The present analyses were restricted to index events, in order to specifically address primary pulmonary complications. Additionally, while previous studies of pediatric patients have reported that high BMI is associated with respiratory compromise during sedation care and during recovery in the post-anesthesia care unit (PACU), the present study demonstrated greater odds of pneumonia and reintubation that included risk time beyond anesthesia care episodes. The post-PACU period, defined as postoperative day 1–3 accounted for more than 50% of all PPCs that occurred within the first 3 postoperative days.

Through use of the NSQIP-P sample, and various elements of study design, these findings have a number of strengths over existing literature. In particular, evaluation of a large sample of pediatric surgical patients across multiple sites, detailed descriptions of patient comorbidities and procedures as well as 30-day observation for a comprehensive complication summary with detailed data describing complication timing [26–28]. Conclusions and causality are also necessarily limited by the design of NSQIP-P. Specifically, due to the retrospective nature of data collection, detailed data describing institutional differences, including anesthetic technique (i.e., regional versus general anesthesia, opioid use, etc.) and postoperative management of pediatric patients are not available. Similarly, this data set likely overlooks subclinical respiratory events such as hypopnea or desaturations, nor does it allow for evaluation of the etiology of respiratory failure necessitating reintubation. In addition, due to the self-elected nature of participating pediatric hospitals, many of which are academic institutions, the hospitals and procedures in NSQIP-P may not be representative of all pediatric surgery nationally. Finally, this investigation demonstrated greater risk of severe pulmonary complications (pneumonia and reintubation) among overweight children, but, due to limitations of NSQIP-P, was not able to describe the magnitude of mild or moderate pulmonary complications or near-miss events among the children studied.

Obese BMI (≥ 95th percentile) patients did not demonstrate greater odds of PPCs in this study. While literature exists to suggest that obesity can be protective in certain situations—such as the obesity paradox demonstrating a mortality benefit in adult cardiac surgery [29]—this does not pertain to respiratory complications; indeed prevailing data demonstrate that obesity is associated with negative respiratory outcomes. As such it is not our intention to trivialize the inherent risks associated with obesity in the perioperative period, but to demonstrate that these risks too can be extended to "overweight" patients. We hypothesize that this lack of association with obesity, described herein may be explained by the availability heuristic [30] wherein obese patients' risk of pulmonary complications is commonly recognized and mitigated through perioperative care strategies. Prior work has demonstrated that obesity coupled with obstructive sleep apnea (OSA) is associated with a greater incidence of adverse respiratory events in children undergoing tonsillectomy [19]. This knowledge has resulted in care redesign at many centers for such high-risk patients including elective admission [8, 31]. It is possible that patients who were markedly obese—due to availability bias—were perceived as "higher risk" by their healthcare team at the time of surgery, and were managed differently by using opioid-sparing approaches, more regional techniques, maintenance of endotracheal intubation, postoperatively or elective hospitalization planned for intensive monitoring of respiratory events. By comparison, patients who were simply overweight may not have been perceived as "high risk" and therefore not managed as aggressively. NSQIP-P has no data describing OSA and no data describing anesthetic or postoperative management, so this explanation is not testable with current data. Future focused investigations may be warranted to specifically test such a hypothesis.

Alternative plausible explanations for the lack of association between obesity and severe PPCs, include a lack of power, however this attribute cannot fully explain these findings, given that obese children were more common than overweight children in our sample. While detailed covariate measurement and rigorous adjustment for surgical case-mix [32] took place, residual confounding may be present in any retrospective analyses. Despite multiple and detailed approaches to case-mix adjustment that would attempt to account for surgical site (e.g., abdominal) as well as organ system (e.g., aerodigestive), residual confounding from case-mix is possible. Additional considerations include the use of BMI, while commonly used to define obesity, it does not account for muscle mass or fat distribution which may be associated with respiratory complications. Akin et al. [33] recently described neck circumference as a better predictor of pulmonary function, and thus pulmonary complications, in obese children as compared to BMI.

In summary, overweight BMI was associated with greater odds of early postoperative pneumonia and unplanned intubation in a diverse pediatric surgical population. These findings extend the literature by demonstrating the risks of severe PPCs across diverse elective surgical procedures and beyond PACU care, up to 7 days postoperatively. Should such findings be replicated by others, it is arguable that this commonly encountered high-risk group may benefit from studies designed to evaluate the impact of tailored anesthetic and perioperative care on these rare, but highly morbid events. While these findings were not replicated in the obese group in our study, they do not minimize the importance of previously described risks in this population. Rather, these findings in a large sample may extend the literature by demonstrating that the known pulmonary risks associated with obesity also significantly impact the "overweight" population. Future work investigating strategies to minimize risk of severe pulmonary complications in overweight children remains critical.

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Compliance with ethical standards

Conflict of interest The authors report no potential financial, commercial or ethical conflicts of interest regarding the contents of this manuscript.

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