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Original Article

Associations between obesity severity and medical comorbidities for children with obesity in low intensity hospital intervention

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ABSTRACT

Background: Childhood obesity has increased dramatically in the United States. Most available research has followed obesity prevalence with little attention to medical comorbidities, which could guide prevention and intervention.
Methods: A retrospective chart review examined 2038 children referred to a Pediatric Weight Management Clinic providing low intensity (<26 contact hours) intervention. Linear regression examined associations between obesity severity level (I, II, III) and blood pressure percentile scores (systolic, diastolic) while controlling for gender, age group, and ethnicity. Logistical regression examined associations between obesity severity level and five medical diagnoses (hypertension, type 2 diabetes, elevated ALT, hyperlipidemia, obstructive sleep apnea), again controlling for demographics.
Results: Results revealed that children with Class III obesity severity had significantly greater risk for five of the seven medical conditions examined, with higher systolic and diastolic blood pressure scores, and higher odds for hypertension, type 2 diabetes, and obstructive sleep apnea.
Conclusion: The US Preventive Services Task Force has documented the effectiveness of intensive behavioral interventions (>26 contact hours for changes in diet, exercise, screen time) for reducing obesity severity in children. Additional research is required to determine whether more intensive behavioral approaches should be added *before* a child's obesity reaches the Class III level of severity in order to prevent medical comorbidities.

The prevalence of obesity in the United States has been increasing since the 1980s, with the latest Centers for Disease Control and Prevention (CDC) brief showing a 9.1% increase in adult obesity and a 4.6% increase in pediatric obesity from 1999 to 2016 [1]. Adult obesity prevalence has followed a steadily increasing course thus far, but youth aged 2–19 years have shown an unexpected plateau from 2003–2004 to 2015–2016, with only statistically insignificant increases in obesity prevalence [2]. Similar plateaus have occurred in developed countries globally [3], but it remains to be seen whether this statistical stabilization will last. Continued obesity tracking is vital.

It remains particularly important to follow obesity trends in the pediatric population. Childhood obesity has been associated with subsequent adulthood obesity, chronic diseases, and high medical costs [4,5], and effective prevention of this progression requires careful identification and treatment of at-risk children. Demographic factors like age, gender, and ethnicity have been shown to strongly influence the prevalence of pediatric obesity. For example, compared to non-Hispanic white adolescents, non-Hispanic black and Hispanic adolescents have shown significantly higher prevalence of obesity as a whole [6], while Hispanic boys and non-Hispanic black girls have shown significantly higher prevalence of severe obesity [7]. Obesity incidence—its *onset*—is also higher in younger children than in older children, with a systematic review of nationally representative data from multiple studies finding that median annual obesity incidence was 4.0%, 3.2%, and 1.8% respectively for preschoolers (2–4 years), school-aged children (5–12 years), and adolescents (13–18 years) [4]. These findings suggest that the problem of US obesity starts in early childhood, with certain gender-ethnicity groups more vulnerable than others. Deeper understanding of childhood obesity will help public health pro-

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grams more strategically target their resources and thus improve health for all ages, genders, and races.

Unfortunately, several barriers have hindered researchers from elucidating the complexities of childhood obesity. Differential definitions of childhood obesity and comorbidities, differences in study methods from surveys to chart reviews [8], and the simple difficulty of recruiting children to engage in a socially complicated, sensitive topic [9] are only a few of the challenges. As an example, early studies indicated that (similar to adults) greater severity of pediatric obesity was associated with greater risk of comorbidities, from hypertension to dyslipidemia to clustering of cardiometabolic factors [10]. However, these early studies used a wide variety of definitions of "severe obesity," from BMI > 95th percentile to BMI > 99th percentile to BMI > 1.0% of 95th percentile to BMI $\geq$ 35 kg/m^2. Conclusions and recommendations were inevitably confusing for clinicians. Only recently has a logical, potentially comorbidity-relevant system of BMI severity classification arisen, recommended by the US Preventive Services Task Force (USPSTF) [11–13]. In this framework, obesity severity is classified based on BMI percentile's relation to the 95th BMI percentile score for same-gender agemates: Class I (95 %–119% of the 95th BMI%), Class II (120%–139 % of the 95th BMI%), or Class III (>1.0% of the 95th BMI%).

To our knowledge, only a few studies have used the currently recommended BMI severity schema to examine comorbidities. One study of children aged 3–19 years in the 1999–2012 National Health and Nutrition Examination Survey (NHANES) found that youth with Class III obesity had over a 2-fold increased risk of hyperglycemia and hypertension compared to youth with Class I obesity [14]. A separate study found that, for youth aged 6–19 years from the same NHANES dataset, the odds for hypertension, hypercholesterolemia, and fasting hyperglycemia progressively doubled with every increase in BMI category from normal to overweight to Class I, II, and III obesity [15]. Lastly, a 2018 study found that Class III obesity was associated with increased risk for cardiovascular risk factor clustering compared with overweight (85th–95th percentile BMI) [16].

Pediatric obesity produces serious comorbidities in childhood that often continue into adulthood, threatening the wellbeing of those affected and placing an ever-growing burden on the health care system [17]. These comorbidities and their onset remain yet to be fully investigated in pediatric populations, and a more robust focus on this area could potentially provide valuable information for early prevention and intervention strategies. Narrowing down the Class level of the severity of obesity at which these comorbidities emerge could especially sharpen the focus of said strategies.

Purpose of present study

The 2017 Recommendations from the USPSTF [11] found support for the effectiveness of intensive behavioral interventions for reducing children's obesity severity. Such intensive behavioral programs, defined by at least 26 contact-hours in a 6–12 month period, typically target behaviors associated with increased obesity risk, promoting changes such as increases in exercise, increases in fruit and vegetable consumption, decreases in high-calorie snack foods, and decreases in sedentary screen time. Their intervention approach typically includes identifying and changing antecedents for such risk-associated behaviors. However, because many pediatric weight management clinics lack the resources to develop such intensive behavioral programs, they typically offer more low intensity interventions that include fewer clinic visits to monitor children's medical conditions (such as blood pressure, diabetes, hyperlipidemia, sleep apnea) and meetings with a clinician to receive feedback and advice about healthier behaviors.

The present study provides one of few available examinations of the association between pediatric obesity severity and medical comorbidities for children referred to pediatric weight management receiving the more typically available low-intensity intervention approaches. The purpose of the study was to examine how these children's obesity severity was associated with seven medical conditions: systolic blood pressure percentile (SBP%), diastolic blood pressure percentile (DBP%), hypertension, type 2 diabetes, elevated ALT scores as an indicator of liver function, hyperlipidemia, and obstructive sleep apnea. The severity of children's obesity severity was defined with the currently recommended Obesity Classes I-III based on their BMI percentile's relation to the 95th BMI percentile score for same-gender agemates [11–13]. Current literature shows that obesity severity level is most consistently associated with increased risk for medical comorbidities [10,14–16]. Therefore, the identification of the obesity severity level and its associated risk of medical co-morbidities could guide physicians working in low-intensity intervention settings as to when they should consider adding or referring to a program with more intensive behavioral interventions to have the best chance for *preventing* comorbidity development in children with obesity.

Methods

Participants

Study participants included 2038 children with obesity referred by primary care clinicians and pediatric specialists to a South-Central Pennsylvania Children's Hospital-based Pediatric Weight Management Clinic (53.0% female; 38.9% White, 13.5% Hispanic, 12.4% Black, 35.3% other ethnicity identification). Children fell into three age groups: 2–5 years old (n = 154), 6–11 years old (n = 880), and 12–17 years old (n = 1004). Children from each of these age groups also fell into three levels of obesity severity (I, II, III) as described below and based on their body mass index percentile (BMI%) score compared to the 95th BMI% score for their same-gender agemates [11–13].

Among the 2081 first-visit records for patients aged 2–17 years referred to the Pediatric Weight Management Clinic during 2010–2018, patients without obesity (BMI% < 95, n = 43) were excluded, leaving 2038 children for the present study sample. Additionally, patients for whom SBP% (n = 27) or DBP% (n = 30) were not recorded at their first visit were excluded from the blood pressure percentile analyses, leaving 2011 and 2008 persons respectively for these analyses.

Procedures and measurement

The Institutional Review Board at the academic institution's Human Subjects Protection Office approved procedures included in the present study. Retrospective chart reviews for the children's first visit to the Pediatric Weight Management Clinic were used to gather demographic information (age, gender, ethnicity) height, weight, blood pressure, and diagnosis for five medical conditions (hypertension, type 2 diabetes, elevated ALT, hyperlipidemia, sleep apnea). Height was measured by clinic staff using a stadiometer, and weight was measured with a digital scale. Blood pressure was measured by manual sphygmomanometer using a Welch Allyn blood pressure cuff of the appropriate cuff size. Blood pressures were measured on children after they had been sitting down for at least five minutes.

To determine obesity severity level (I, II, III), the child's body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m^2), then the child's BMI was compared to agemates from CDC growth charts [18,19] to classify

Table 1
Prevalence of demographics and medical conditions for 2038 children with obesity, shown separately by age and obesity severity.

Age:		2–5 years			6–11 years			12–17 years		
		(n = 154)			(n = 880)			(n = 1004)		
Obesity level:		I (n = 29) %	II (n = 47) %	III (n = 78) %	I (n = 242) %	II (n = 314) %	III (n = 324) %	I (n = 250) %	II (n = 365) %	III (n = 389) %
Gender:										
	Male	46.2%	38.3%	46.2%	40.9%	48.1%	54.6%	40.0%	45.8%	50.4%
	Female	53.8%	61.7%	53.8%	59.1%	51.9%	45.4%	60.0%	54.2%	49.6%
Ethnicity:										
	Black	13.8%	6.4%	12.8%	9.5%	13.4%	15.7%	10.0%	11.5%	13.6%
	Hispanic	13.8%	14.9%	21.8%	12.0%	15.3%	14.2%	14.4%	12.3%	11.1%
	Other	34.5%	44.7%	23.1%	37.2%	34.7%	34.6%	35.6%	34.0%	37.3%
	White	37.9%	34.0%	42.3%	41.3%	36.6%	35.5%	40.0%	42.2%	38.0%
Hypertension		0.0%	0.0%	0.0%	0.0%	1.6%	3.4%	1.6%	2.2%	7.7%
Diabetes		0.0%	0.0%	0.0%	1.0%	4.0%	4.0%	2.0%	1.4%	6.2%
Elevated ALT		6.9%	6.4%	6.4%	6.6%	7.0%	10.5%	6.4%	7.1%	9.0%
Hyperlipids		27.6%	17.0%	30.8%	37.2%	36.3%	36.1%	34.8%	38.4%	35.2%
Sleep apnea		3.4%	8.5%	12.8%	1.7%	5.4%	11.4%	4.4%	4.4%	13.6%
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
SBP%		66.9% (25.1%)	60.1% (29.6%)	66.8% (27.1%)	53.9% (27.8%)	59.9% (26.0%)	67.4% (27.3%)	67.4% (27.3%)	64.3% (26.3%)	69.8% (27.2%)
DBP%		69.5% (22.7%)	70.1% (17.6%)	71.1% (23.7%)	51.3% (24.9%)	56.1% (22.5%)	60.9% (23.8%)	55.6% (22.5%)	56.8% (23.7%)	62.9% (24.2%)

the child as having obesity (BMI ≥ 95th percentile). Finally, obesity severity level (I, II, III) was calculated as the child's BMI% score divided by the 95th BMI% score for same-gender agemates: Class I (95%–119% of the 95th BMI%), Class II (120%–139% of the 95th BMI%), or Class III (>1.0% of the 95th BMI%) [11–13].

Seven medical conditions were evaluated for each child's first clinic visit: two blood pressure percentile scores compared to same-gender agemates (SBP%, DBP%), and diagnosis of five medical conditions chosen as potential indicators of cardiovascular, metabolic, liver, and life quality problems (hypertension, type 2 diabetes, elevated ALT, hyperlipidemia, and obstructive sleep apnea). The child's SBP% and DBP% scores were determined relative to same-gender agemates as guided by the Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents [20] with values at or above the 95th percentile considered hypertensive. The medical diagnosis of hypertension was determined by the clinic physician guided by the Fourth Report as described above [20], type 2 diabetes was determined as two separate measurements of hemoglobin A1C levels greater than or equal to 6.5%, hyperlipidemia was defined as guided by the 2011 statement of the National Heart, Lung, and Blood Institute [21], and elevated ALT levels were defined as U/L greater than 22 for girls and greater than 26 for boys [22]. Finally, sleep apnea was determined from polysomnography conducted in a sleep lab at the medical center and read by a pediatric pulmonologist. Criteria for diagnosis were based on the American Academy of Sleep Medicine, with apnea-hypopnea index (AHI) scores per hour of total sleep time (hrTST) interpreted as either normal sleep (AHI ≤ 1/hrTST), mild sleep apnea (AHI 1–5, moderate sleep apnea (AHI 5–10), or severe sleep apnea (AHI > 10/hrTST) [23].

Table 1 shows descriptive statistics for the demographics and medical conditions of the present sample of 2038 children, shown separately for three age groups (2–5 years, 6–11 years, 12–17 years) and shown separately for the three levels of obesity severity within each age group (I, II, III).

Data analysis

The goal for data analysis of the present study was to examine associations between children's obesity severity (I, II, III) and each of seven medical conditions, while controlling for children's demographics (gender, age group, ethnic group). For each of the two blood pressure measures (SBP%, DBP%), SPSS 24 was used to conduct linear regression analysis with the blood pressure percentile serving as the outcome variable, with dummy coding (0, 1) used for male gender as a predictor variable to compare it to female gender, with dummy coding (0, 1) used for each age group as a predictor variable (6–11 years, 12–17 years) to compare it to the 2–5 years age group, with dummy coding used for each ethnic group as a predictor variable (Black, Hispanic, Other) to compare it to the White ethnic group, and finally with dummy coding (0,1) used for each obesity severity level as a predictor variable (level II, level III) to compare it to level I of obesity severity. For these linear regression analyses, a criterion value of $p < 0.05$ was used to determine statistical significance. Also, the significance of obesity level as a predictor of SBP% or DBP% was calculated *after* demographic variables (gender, age group, ethnic group) were taken into account. Finally, significant *beta* values shown for each group within a predictor variable indicated how much and in which direction the outcome variable tended to change in association with that group compared to the designated baseline group, with *positive* beta values indicating increases in the blood pressure outcome, and *negative* beta values indicating decreases in the blood pressure outcome (See Table 2).

For each of the five medical diagnoses (hypertension, type 2 diabetes, elevated ALT, hyperlipidemia, sleep apnea), SPSS 24 software was used to conduct logistical regression analysis with the diagnosis (0 = no, 1 = yes) serving as the outcome variable, coding gender as a predictor variable (1 = male, 2 = female) so that the *higher code* for female would serve as the comparison group, coding age as a predictor variable (1 = 12–17 years, 2 = 6–11 years, 3 = 2–5 years) so that the *highest code* for 2–5 years would serve as the comparison group, coding ethnic group as predictor variable (1 = Black, 2 = Hispanic, 3 = Other, 4 = White) so that the *highest code* for White would serve as the comparison group, and coding obesity severity as a predictor variable (1 = Class III, 2 = Class II, 3 = Class I) so that the *highest code* for Class I would serve as the comparison group. For these logistical regression analyses, a criterion value of $p < 0.05$ was used to determine statistical significance. Also, the significance of obesity level as a predictor of the medical diagnosis was calcu-

Table 2
Linear regression to examine association of obesity severity and two blood pressure measures for 2038 children with obesity, controlling for demographics (gender, age, ethnicity).

	Systolic BP percentile (SBP%)			Diastolic BP percentile (DBP%)		
	beta	*t*	*p*	*beta*	*t*	*p*
Demographics:						
Gender:						
Male (vs. female)	−0.036	1.64	0.102	0.021	0.97	0.332
Age group:						
6–11 years (vs. 2–5 years)	−0.042	0.98	0.324	−0.268	6.29	0.000
12–17 years (vs. 2–5 years)	0.023	0.55	0.584	−0.227	5.33	0.000
Ethnic group:						
Black (vs. White)	−0.020	0.84	0.399	−0.015	0.62	0.536
Hispanic (vs. White)	0.025	1.07	0.283	−0.008	0.33	0.745
Other (vs. White)	0.077	3.21	0.001	−0.023	0.96	0.337
Obesity severity:						
Class II (vs. Class I)	0.095	3.52	0.000	0.055	2.03	0.042
Class III (vs. Class I)	0.213	7.84	0.000	0.160	5.87	0.000
	$R^2 = 0.041$			$R^2 = 0.041$		
	$F_{(8,2029)} = 10.96$			$F_{(8,2029)} = 10.84$		
	$p = 0.000$			$p = 0.000$		

lated *after* demographic variables (gender, age group, ethnic group) were taken into account. Finally, significant "odds ratio" values shown for each group within a predictor variable [*Exp(B)*] indicated whether the "odds" of the diagnosis were increased (if *Exp(B)* > 1.00) or decreased (if *Exp(B)* < 1.00) for children in that group compared to the designated baseline group (See Table 3).

Results

Blood pressure

Linear regression analysis revealed that significantly higher **SBP%** scores were shown by children with Class II and Class III obesity severity than by children with Class I severity (*beta* = 0.095, *beta* = 0.213, respectively), after taking into account demographics (gender, age, ethnicity). Additionally, significantly higher SBP% scores were also seen for children in the Other ethnicity group than for children with White ethnicity (*beta* = 0.077). None of the other demographic variables were significantly associated with SBP% (See Table 2).

Linear regression analysis also revealed that significantly higher **DBP%** scores were shown by children with Class II and III obesity severity than by children with Class I severity (*beta* = 0.055, *beta* = 0.160, respectively), after taking into account demographics (gender, age, ethnicity). Additionally, significantly lower DBP% scores were seen for children 6–11 years and 12–17 years old than for children 2–5 years old (*beta* = −0.268, *beta* = −0.227, respectively). None of the other demographic variables were significantly associated with DBP% (See Table 2).

Medical diagnoses

Logistical regression analysis found significantly higher probability for **hypertension** in children with Class II and III obesity severity than in children with Class I severity, after taking into account demographics (gender, age, ethnicity). Specifically, the odds of hypertension were 6.94 times higher for children with Class III severity than for Class I severity. None of the demographic variables were significantly associated with the odds for a hypertension diagnosis (See Table 3).

Logistical regression analysis found significantly higher probability for **type 2 diabetes** in children with Class III obesity severity than in children with Class I severity, after taking into account demographics (gender, age, ethnicity). Specifically, the odds of diabetes were 5.12 times higher for children with Class III severity than for Class I severity. Additionally, children with Black and Other ethnicity had higher probability for diabetes than White children, with the odds of diabetes being 4.91 times higher for Black children and 2.68 times higher for Other children. None of the other demographic variables were significantly associated with the odds for a diabetes diagnosis (See Table 3).

Logistical regression analysis found no significant differences in the probability for **elevated ALT** between Class II or Class III and the comparison group of Class I. However, the demographic variables of gender and ethnicity were significantly associated with the probability of a diagnosis of elevated ALT. Specifically, the odds for male children having elevated ALT were 1.52 times higher than for females. In comparison to White children, children with Black and Other ethnicity showed *reduced* probability of elevated ALT, with the odds for Black children being 0.26 of those for White children, and the odds for Other children being 0.63 of those for White children. None of the other demographic variables were significantly associated with the odds for a diagnosis of elevated ALT (See Table 3).

Logistical regression analysis found no significant differences in the probability for **hyperlipidemia** between Class II or Class III and the comparison group of Class I. However, the demographic variables of age and ethnicity were significantly associated with the probability of hyperlipidemia diagnosis. Specifically, in comparison to the youngest children aged 2–5 years, the odds for hyperlipidemia were 1.67 times higher for children aged 6–11 years, and 1.65 times higher for children aged 12–17 years. Also, compared to White children, children with Black and Other ethnicity showed reduced probability of hyperlipidemia, with the odds for Black children being 0.73 of those for White children, and the odds for Other children being 0.64 of those for White children. None of the other demographic variables were significantly associated with the odds for a diagnosis of hyperlipidemia (See Table 3).

Logistical regression analysis found significantly higher probability for **obstructive sleep apnea** in children with Class III obesity severity than in children with Class I severity, after taking into account demographics (gender, age, ethnicity). Specifically, the odds of obstructive sleep apnea were 4.32 times higher for children with Class III severity than for Class I severity. None of the demographic variables were significantly associated with the odds for an obstructive sleep apnea diagnosis (See Table 3).

Table 3
Logistical regression to examine association of obesity severity and diagnosis of five medical conditions for 2038 children with obesity, controlling for demographics (gender, age, ethnicity).

	Hyper-tension			Type 2 diabetes			Elevated ALT		
	Beta	*Exp(B)*	*p*	*Beta*	*Exp(B)*	*p*	*Beta*	*Exp(B)*	*p*
Demographics:									
Gender:									
Males (vs. females)	0.21	1.24	0.433	−0.52	0.60	0.089	0.42	1.52	0.013
Age group:									
6–11 (vs. 2–5)	17.29	–	0.996	17.27	–	0.996	0.32	1.38	0.362
12–17 (vs. 2–5)	18.13	–	0.995	17.89	–	0.995	0.24	1.27	0.494
Ethnic group:									
Black (vs. White)	0.45	1.57	0.242	1.59	4.91	0.000	−1.35	0.26	0.001
Hispanic (vs. White)	−0.56	0.57	0.310	0.38	1.46	0.537	0.02	1.02	0.932
Other (vs. White)	0.12	1.13	0.706	0.99	2.68	0.014	−0.45	0.64	0.020
Obesity severity:									
Class II (vs. Class I)	0.82	2.28	0.153	0.12	1.13	0.832	0.07	1.07	0.774
Class III (vs. Class I)	1.94	6.94	0.000	1.63	5.12	0.001	0.39	1.48	0.072
	Nagelkerke $R^2 = 0.108$ $Chi^2 = 50.65$ $df = 8$ $p = 0.000$			Nagelkerke $R^2 = 0.140$ $Chi^2 = 59.54$ $df = 8$ $p = 0.000$			Nagelkerke $R^2 = 0.037$ $Chi^2 = 31.70$ $df = 8$ $p = 0.000$		

	Hyper-lipidemia			Sleep apnea		
	Beta	*Exp(B)*	*p*	*Beta*	*Exp(B)*	*p*
Demographics:						
Gender:						
Males (vs. females)	0.09	1.09	0.362	0.24	1.27	0.161
Age group:						
6–11 (vs. 2–5)	0.51	1.67	0.010	−0.27	0.76	0.379
12–17 (vs. 2–5)	0.50	1.65	0.011	−0.07	0.94	0.826
Ethnic group:						
Black (vs. White)	−0.31	0.73	0.040	0.41	1.51	0.099
Hispanic (vs. White)	−0.03	0.98	0.860	0.32	1.37	0.211
Other (vs. White)	−0.44	0.64	0.000	−0.12	0.89	0.566
Obesity severity:						
Class II (vs. Class I)	0.03	1.03	0.883	0.50	1.65	0.103
Class III (vs. Class I)	0.003	1.00	0.978	1.46	4.32	0.000
	Nagelkerke $R^2 = 0.018$ $Chi^2 = 26.98$ $df = 8$ $p = 0.001$			Nagelkerke $R^2 = 0.070$ $Chi^2 = 59.62$ $df = 8$ $p = 0.000$		

Discussion

The present study examined associations between obesity severity and seven possible medical comorbidities for a diverse group of 2038 children with obesity referred to low-intensity hospital intervention. The medical comorbidities considered were two blood pressure percentile scores (SBP%, DBP%) and five medical diagnoses (no/yes) of hypertension, type 2 diabetes, elevated ALT, hyperlipidemia, and obstructive sleep apnea. While controlling for the effect of demographic variables (gender, age, ethnicity), regression analyses revealed that Class III obesity severity was the most consistent predictor, showing significant associations with five of the seven medical conditions. More specifically, children with Class III obesity severity (defined as >1.0% of the 95th BMI% for same-gender agemates) had significantly higher SBP% and DBP% scores, and they had significantly higher odds for hypertension, type 2 diabetes, and obstructive sleep apnea in comparison to children with Class I obesity severity. Our results as a whole are consistent with the current literature examining risk of comorbidities by the same recommended obesity severity classification. While prior studies have demonstrated increased risk of hyperglycemia, fasting hyperglycemia, hypertension, and hypercholesterolemia in Class III obesity compared to Class I Obesity [14,15], the clinical diagnoses of type 2 diabetes and obstructive sleep apnea and the numerical measures of SBP% and DBP% have not yet, to our knowledge, been studied in association with class of obesity severity. Given that the Class III level of obesity severity was consistently associated with medical comorbidities for 2038 children with obesity 2–17 years of age, results from the present study call for further research to determine whether more intensive behavioral approaches [11] added before a child reaches Class III obesity may prevent medical comorbidities.

Besides obesity severity, the demographic variables of age, ethnicity, and gender were significantly associated with the medical conditions considered in the present study. Compared to children 2–5 years of age, children 6–11 and 12–17 years of age showed higher DBP% scores and higher risk for a diagnosis of hyperlipidemia. Compared to White children, Other ethnicity children showed higher scores for SBP%, and Black and Other ethnicity children showed higher risk for a diagnosis of type 2 diabetes. Finally, males showed higher risk than females for the diagnosis of elevated ALT. These results are also generally consistent with the current literature. Prior studies have demonstrated significantly greater prevalence of obesity in children 6–11 and 12–19 years old than in children 2–5 years old [24], as well as greater prevalence of obesity in non-Hispanic black adolescents and Hispanic adolescents than in non-Hispanic white adolescents [6]. While the separate effects of gender, ethnicity, and age on our seven specific measures of obesity-related comorbidities have not yet, to our knowledge, been fully studied, the well-established link between obesity and its comorbidities [17] renders it unsurprising that established groups with high risk of obesity are the same groups with increased risk for

our examined comorbidities. This research suggests that treating the obesity class in younger children earlier and more aggressively may prevent obesity-related comorbidities. Therefore, additional research is required to determine whether male children, children 6–17 years of age, and children with Black or Other ethnicity should be referred for high-intensity obesity treatment at a lower Obesity Class level (Class I or Class II) to reduce and prevent the risk of obesity-related comorbidities.

Study limitations and suggestions for future research

One limitation of the present study was that it did not include a group of children *without* obesity to serve as a comparison group for the prevalence and risks of the seven medical conditions evaluated (SBP%, DBP%, hypertension, type 2 diabetes, elevated ALT, hyperlipidemia, sleep apnea). Future research should include a large comparison group of children without obesity. Another study limitation was that all 2038 children with obesity in the present sample came from only one pediatric weight management clinic in Pennsylvania. Future research should examine whether the present patterns of associations between obesity severity and medical comorbidities are replicated with children from other clinic locations.

Finally, the present study offers a *cross-sectional* examination of how obesity severity is associated with medical comorbidities in children with obesity. However, confidence in the patterns found in present results would be enhanced by *longitudinal* studies that examine how medical comorbidities of children change across time as they move to more or less severe levels of obesity. Also, future *experimental* studies could examine how children with obesity randomly assigned to control conditions or intensive behavioral conditions show differences in not only their weight status, but also the status of their medical conditions.

Ethical statement

I, Marsha B. Novick, MD, have read and have abided by the statement of ethical standards for manuscripts submitted to the *Obesity Research & Clinical Practice*.

Declarations of interest

None.

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