Change in Weight Status and Development of Hypertension

Emily D. Parker, PhD, MPH,[a] Alan R. Sinaiko, MD,[b] Elyse O. Kharbanda, MD, MPH,[a] Karen L. Margolis, MD, MPH,[a] Matt F. Daley, MD,[c] Nicole K. Trower, BS,[a] Nancy E. Sherwood, PhD,[a,d] Louise C. Greenspan, MD,[e] Joan C. Lo, MD,[f] David J. Magid, MD, MPH,[c] Patrick J. O'Connor, MD, MA, MPH[a]

abstract

OBJECTIVE: To examine the association of BMI percentile and change in BMI percentile to change in blood pressure (BP) percentile and development of hypertension (HTN).

METHODS: This retrospective cohort included 101 606 subjects age 3 to 17 years from 3 health systems across the United States. Height, weight, and BPs were extracted from electronic health records, and BMI and BP percentiles were computed with the appropriate age, gender, and height charts. Mixed linear regression estimated change in BP percentile, and proportional hazards regression was used to estimate risk of incident HTN associated with BMI percentile and change in BMI percentile.

RESULTS: The largest increases in BP percentile were observed among children and adolescents who became obese or maintained obesity. Over a median 3.1 years of follow-up, 0.3% of subjects developed HTN. Obese children ages 3 to 11 had twofold increased risk of developing HTN compared with healthy weight children. Obese children and adolescents had a twofold increased risk of developing HTN, and severely obese children had a more than fourfold increased risk. Compared with those who maintained a healthy weight, children and adolescents who became obese or maintained obesity had a more than threefold increased risk of incident HTN.

CONCLUSIONS: We observed a strong, statistically significant association between increasing BMI percentile and increases in BP percentile, with risk of incident HTN associated primarily with obesity. The adverse impact of weight gain and obesity in this cohort over a short period underscores the early need for effective strategies for prevention of overweight and obesity.

FREE NIH

[a]HealthPartners Institute for Education and Research, HealthPartners, Minneapolis, Minnesota; [b]Department of Pediatrics, and [d]Division of Epidemiology and Community Health, University of Minnesota, Minneapolis, Minnesota; [c]Institute for Health Research, Kaiser Permanente Colorado, Denver, Colorado; [e]Department of Pediatrics, Kaiser Permanente San Francisco, San Francisco, California; and [f]Division of Research, Kaiser Permanente Northern California, Oakland, California

Dr Parker conceptualized the study design, assembled the data set, conducted all analyses, and drafted the initial manuscript; Dr Sinaiko conceptualized the overall study that developed these data, assisted in the development of the current study, and edited the manuscript; Dr Kharbanda contributed to study conceptualization and design and critically reviewed and provided feedback on the manuscript; Dr Margolis contributed to the study design and provided critical review for drafts of the manuscript; Drs Daley and Sherwood and Ms Trower contributed to the data collection and analysis and critically reviewed the final manuscript; Dr Greenspan contributed to data collection and critically reviewed and provided feedback on the manuscript; Dr Lo contributed to the cohort assembly and data collection, critically reviewed study results, and provided content edits to the manuscript; Dr Magid participated in assembling the data set and reviewed study results and the initial manuscript; Dr O'Connor conceptualized the overall study and development of the current study, reviewed study results, and critically reviewed the manuscript; and all authors approved the final manuscript as submitted.

DOI: 10.1542/peds.2015-1662

WHAT'S KNOWN ON THIS SUBJECT: Childhood obesity is strongly associated with hypertension in childhood, and there is a strong independent tracking effect for both BMI and blood pressure into young adulthood.

WHAT THIS STUDY ADDS: Even in healthy weight children, an increase in BMI increases blood pressure, but hypertension is related to development or maintenance of obesity. These changes occurred within a short time frame, underscoring the need for early strategies for obesity prevention.

To cite: Parker ED, Sinaiko AR, Kharbanda EO, et al. Change in Weight Status and Development of Hypertension. *Pediatrics.* 2016;137(3):e20151662

Nearly one-third of children and adolescents in the United States are overweight or obese.[1] Although these rates have stabilized recently, they represent a dramatic increase over the past 40 years. Childhood obesity is strongly associated with hypertension (HTN).[2] As recently reviewed,[3] epidemiologic studies conducted primarily in junior and senior high school students have reported HTN prevalence rates ranging between 0.8% and 3.2%, with HTN prevalence >10% in obese students. Studies conducted in ambulatory practices within large health care systems and including grade school children have reported overall HTN prevalence rates of 0.3% to 0.9% in healthy weight children and 1.0% to 9.2% in obese children.[4–6]

Because of the relationship of both obesity and HTN in childhood to the development of adult cardiovascular disease, clarifying the interaction between the 2 has the potential to reduce cardiovascular disease. Both blood pressure (BP) and BMI have been shown to have a significant tracking effect between childhood and adulthood.[7–9] Previous studies have reported significant associated changes in BMI and BP from childhood to early adolescence[10,11] and in BMI and BP from adolescence to mean age 29 years.[12] Other studies have demonstrated a strong association between change in BMI *z* score and change in BP in adolescents.[13–15] In a recent meta-analysis of cross-sectional studies of BMI and cardiovascular disease risk factors in otherwise healthy children, overweight and obese children had systolic BPs 4.5 and 7.5 mm Hg higher compared with healthy weight children.[16] Given the prevalence of children and adolescents at risk for overweight and obesity, it is pertinent to investigate the longitudinal relationships between BP and BMI to understand the degree to which BMI and changes in BMI influence BP changes. The objective of this study, conducted in a large ambulatory cohort of children and adolescents from 3 regions of the United States, was to determine the relation of BMI percentile and change in BMI percentile with change in BP percentile and development of HTN.

METHODS

Study Setting

This retrospective cohort study was conducted in 3 geographically diverse integrated health care delivery systems that together provide care for >4 million people: HealthPartners Medical Group in Minnesota, Kaiser Permanente Colorado, and Kaiser Permanente Northern California. All 3 study sites use the EpiCare (Verona, WI) electronic health records (EHRs). The EHRs contain data on demographics, clinical encounters, diagnosis codes, and vital signs. Patient age, gender, health plan enrollment data, and diagnosis codes were obtained for all patients from health plan administrative databases. Self-reported or parent-reported race or ethnicity was obtained from EHR, outpatient registration data, and hospital discharge records and was available for 94% of cohort members. Insurance status was obtained from enrollment records. Data from the 3 sites were restructured into a common, standardized format with identical variable names, definitions, labels, and coding.[17]

Study Population

We identified 195 984 active patients ages 3 to 17 years who were seen between January 1, 2007 and December 31, 2011, had BP measurements, and had height measurements within 90 days of the BP to calculate the BP percentile. Inclusion in this study took ≥6 months of observation time before the baseline measurements to ensure that there were no hypertensive measurements and ≥3 primary care visits with BP measurements during the period of observation (*n* = 109 446). Of these, 345 patients (0.3%) were excluded for having a diagnosis code for HTN in the EMR (International Classification of Diseases, Ninth Revision codes 401–405) before or on their first primary care visit during the study period. Patients who were underweight or became underweight (BMI percentile <5th percentile) during follow-up were excluded (*N* = 7427) because of the possibility of any medical conditions that would affect BP. Patients with missing data on pertinent variables (eg, those included in multivariable models, as noted below in "Analytic Methods") were not included (*N* = 1068). Thus, the final study sample was 100 606.

Exposure and Outcome Measures

The heights, weights, and BPs used in this study were measured during primary care visits as part of routine clinical care. Among children and adolescents 3 to 17 years old in this cohort, BP is routinely measured in >95% of preventive health visits and the majority of acute or follow-up visits. At the 3 study sites, heights and weights were measured with calibrated stadiometers and scales and entered in EpiCare. Age- and gender-specific BMI percentiles were calculated with the year 2000 Centers for Disease Control and Prevention growth charts.[18] BMI was classified into 5 categories: low healthy (5th–49th percentile), high healthy (50th–84th), overweight (85th–94th), obese (95th–98th percentile), and severely obese (≥99th percentile).

At HealthPartners and Kaiser Permanente Colorado, BP was measured primarily with aneroid sphygmomanometers; at Kaiser Permanente Northern California, BP was measured with Welch Allyn (Skaneateles Falls, NY) oscillometric devices. Additional details of BP measurement at the study sites have been published previously.[4,5] BP was entered into EpiCare in mm Hg and converted to age-, gender-, and height-specific percentiles according to the Fourth Report on the Diagnosis, Evaluation and Treatment of High Blood Pressure in Children and Adolescents (Task Force Report).[19] BP measurements taken at hospital inpatient settings, emergency department visits, urgent care, and surgery or specialty outpatient settings were excluded. If >1 BP measurement was entered for a given encounter, the first measurement was used.

HTN was defined according to national guidelines published in Task Force Report.[19] In congruence with the Task Force guidelines, a patient was considered prehypertensive if at least one BP recorded in the EMR was between the 90th and 95th percentile or ≥120/80 mmHg for adolescents. HTN was defined as systolic blood pressure (SBP) or diastolic blood pressure (DBP) ≥95th percentile at ≥3 consecutive clinic visits.

Analytic Methods

All statistical analyses were completed with SAS version 9.3 (SAS Institute, Inc, Cary, NC). First, descriptive characteristics were computed through means and standard deviations for continuous variables and percentages for categorical and binary variables. Results are stratified by age–gender group (girls 3–11 years, boys 3–11 years, girls 12–17 years, boys 12–17 years). Second, the associations between BMI category at baseline and BP percentiles were estimated through generalized linear regression mixed models and adjustment for multiple comparisons via the Tukey honest significant difference test. Models were stratified by age–gender group and adjusted for race, insurance type, year of cohort entry (secular trend), study site, and baseline BP percentile.[20] Third, to estimate the hazard ratio (HR) of developing hypertension, we used a Cox proportional hazards model with time-varying exposures to account for change in BMI percentile over follow-up, before event or censoring. Follow-up time was computed in days from the date of the baseline visit (ie, first visit where inclusion criteria were met) to event (meeting the criteria for hypertension), disenrollment, initiation of anti-HTN medication, death, aging out of the cohort (18 years), or December 31, 2012, whichever occurred first. Multivariable models were adjusted for gender, race, insurance type, year of cohort entry (secular trend), study site, annual visit rate, and baseline SBP percentile and stratified by age. Predictors were BMI category at baseline and change in BMI category over follow-up. To ensure sufficient time for measurement of change in BMI, needed to determine the longitudinal relationship between change in BMI category and BP, we restricted the study population to those with follow-up of ≥2 years (n = 80 829 for these analyses).

Protection of Human Study Subjects

This study was reviewed in advance, approved, and monitored by the HealthPartners Institutional Review Board (IRB). The IRB at HealthPartners Institute for Education and Research approved the study, with ceding of oversight authority by the Kaiser Permanente Colorado and Kaiser Northern California IRBs. The IRBs waived written patient informed consent for this retrospective observational study.

RESULTS

In this cohort of 100 606 children and adolescents, 66 991 (65.6%) were 3 to 11 years old and 33 615 (33.4%) were 12 to 17 years old; 45% were non-Hispanic white (Table 1). Slightly more of the younger children were boys, and slightly more of the adolescents were girls. Median follow-up was 3.1 years (interquartile range 2.0–4.2). The median number of visits per year was 2 (interquartile range 1.2–2.9). At the baseline visit 16% were overweight, 2% were obese, and 4% were severely obese. For SBP at the baseline visit, 92.6% were <90th percentile (normal), 4% were 90th to 9th percentile (prehypertensive), and 4% were at or above the 95th percentile (hypertensive range). Slightly fewer children had prehypertensive or hypertensive levels of DBP.

Baseline BMI and BP Results

Mean SBP percentiles by BMI category (adjusted for race, insurance type, year of cohort entry [secular trend], and study site) at baseline are shown in Table 2. There was a statistically significant linear trend of increasing SBP and DBP percentile with increasing BMI category that was consistent across all age–gender groups. Although obese and severely obese children and adolescents had the highest mean SBP percentiles, the mean was between the 58.6th and 60.8th percentiles, well within the normal range.

Baseline BMI and Risk of Incident HTN Results

Over a median 3.1 person-years' follow-up, a total of 343 (0.3%) subjects newly met clinical criteria for HTN, for an incidence rate of 0.15 per person-year (Table 3). After we adjusted for gender, race, insurance type, year of cohort entry (secular trend), study site, annual visit rate, and baseline SBP percentile, there was no significant difference in development of HTN between the low and high normal categories and between low normal and overweight categories. In contrast, obese children ages 3 to 11 had significantly greater likelihood of developing HTN (HR = 2.02; 95% confidence interval [CI], 1.28–7.04), and the risks in obese adolescents were similarly high (HR

TABLE 1 Descriptive Characteristics, Means, and SDs or Percentage of Normotensive Population at Start of Observation

	Total	3- to 11-y-Olds		12- to 17-y-Olds	
		Girls	Boys	Girls	Mean
N	101 606	32 041	34 950	18 780	14 835
Race and ethnicity, %					
White	45	43	43	50	50
African American	11	11	11	11	10
Asian American	12	13	14	9	10
Hispanic	16	16	16	17	15
Other or multi	10	10	9	9	10
Unknown or not asked	6	6	7	5	5
Government insurance, %	4	4	5	4	3
No. visits/y (median)	1.8	1.8	1.9	1.7	1.4
Follow-up time, y (median)	3.1	3.5	3.5	2.4	2.5
BMI percentile, mean (SD)	65.0 (26.8)	62.8 (27.1)	64.7 (27.1)	67.2 (25.3)	67.3 (26.9)
Low healthy (5th–49th), %	30	33	31	26	28
High healthy (50th–84th), %	38	39	37	42	36
Overweight (85th–95th), %	16	16	16	18	17
Obese (95th–98th), %	12	10	12	12	15
Severely obese (≥99th), %	4	3	4	2	4
SBP percentile, mean (SD)	47.3 (27.5)	49.2 (26.7)	48.3 (26.5)	43.1 (28.9)	45.3 (28.9)
<90th percentile, %	93	92	93	93	92
90–<95th percentile, %	4	4	4	3	4
95th percentile, %	4	4	3	3	4
DBP percentile, mean (SD)	53.1 (23.7)	54.3 (4.0)	56.2 (23.2)	46.6 (23.7)	50.7 (23.2)
<90th percentile, %	94	94	93	96	96
90–<95th percentile, %	4	4	4	3	3
95th percentile, %	2	3	2	1	1
Cohort entry year, %					
2007	46	45	45	48	49
2008	28	28	27	28	28
2009	15	16	16	15	14
2010	8	8	9	7	7
2011	3	3	3	2	2

= 2.20; 95% CI, 1.24–3.91). Compared with low healthy weight, children and adolescents who were severely obese were 4.42 (95% CI, 2.77–7.04) and 4.46 (95% CI, 2.39–8.31) times more likely to develop HTN.

Because the criteria for HTN require 3 separate visits, it is possible that children with more clinic visits will be identified as hypertensive simply because they will have had more BP measurements. To examine whether the inclusion criterion of ≥3 visits imposed any selection bias, we conducted a sensitivity analysis changing the inclusion criteria to ≥2 visits. When we changed the inclusion criterion to ≥2 visits, only 8 additional cases of HTN were found.

TABLE 2 Mean and SE BP Percentile[a] Associated With BMI Category[b] at Baseline

	Total	SBP Percentile		DBP Percentile	
		Girls	Boys		
Children ages 3–11 y					
Low normal wt	41.9 (0.4)	45.4 (0.4)	45.2 (0.4)	53.7 (0.4)	56.7 (0.4)
High normal wt	45.7 (0.4)	49.4 (0.4)	47.4 (0.4)	55.2 (0.4)	56.8 (0.4)
Overweight	50.6 (0.4)	53.5 (0.5)	50.7 (0.5)	63.8 (0.8)	58.0 (0.5)
Obese	57.5 (0.4)	58.5 (0.6)	57.2 (0.5)	59.8 (0.5)	59.4 (0.5)
Severely obese	63.8 (0.6)	63.7 (0.9)	62.6 (0.7)	63.8 (0.8)	65.2 (0.7)
P for linear trend	<.0001	<.0001	<.0001	<.0001	<.0001
Adolescents 12–17 y					
Low normal wt	51.6 (0.4)	36.2 (0.5)	37.9 (0.5)	44.5 (0.45)	49.6 (0.5)
High normal wt	52.6 (0.3)	41.5 (0.5)	44.2 (0.5)	46.9 (0.4)	51.1 (0.5)
Overweight	54.8 (0.4)	49.1 (0.6)	50.4 (0.6)	50.5 (0.5)	53.3 (0.6)
Obese	58.1 (0.4)	58.0 (0.7)	58.8 (0.7)	56.5 (0.6)	59.1 (0.6)
Severely obese	63.5 (0.5)	69.1 (1.3)	67.2 (1.1)	64.6 (1.1)	65.9 (1.0)
P for linear trend	<.0001	<.0001	<.0001	<.0001	<.0001

[a] Adjusted for race, insurance type, year of cohort entry (secular trend), study site, annual visit rate, and baseline SBP percentile.

[b] BMI categories: Low healthy wt, 5th–49th percentile; high healthy wt, 50th–84th percentile; overweight, 85th–94th percentile; obese, 95th–99th percentile, severely obese, ≥99th percentile.

TABLE 3 HRs and 95% CIs[a] for the Association Between Baseline BMI Category[b] and Incident HTN Over Median 3.1-y Follow-up

BMI Category[b]	Children 3–11 y				Adolescents 12–17 y			
	No. Cases Incident HTN	Person-Years Follow-Up	HR	95% CI	No. Cases Incident HTN	Person-Years Follow-Up	HR	95% CI
Low healthy wt	35	55 859	1.00 Reference		17	18 612	1.00 Reference	
High healthy wt	35	66 696	0.72	0.45–1.14	29	26 185	0.93	0.51–1.70
Overweight	35	27 012	1.42	0.88–2.27	26	11 745	1.41	0.76–2.62
Obese	44	17 926	2.02	1.28–3.18	47	8710	2.2	1.24–3.91
Severely obese	44	5833	4.42	2.77–7.04	31	2037	4.46	2.39–8.31
P for linear trend			<.0001				<.0001	

[a] Adjusted for gender, race, insurance type, year of cohort entry (secular trend), study site, annual visit rate, and baseline SBP percentile.

[b] BMI categories: Low healthy wt, 5th–49th percentile; high healthy wt, 50th–84th percentile; overweight, 85th–94th percentile; obese, 95th–99th percentile, severely obese, ≥99th percentile.

Change in BMI and BP Results

Tables 4 and 5 show the changes in BMI from baseline to follow-up. Among the children and adolescents with healthy BMI at baseline, 80% and 87%, respectively maintained healthy weight status, and 0.3% and 0.1%, respectively, increased from normal to obese or severely obese. Among children and adolescents who were overweight at baseline, 36% and 52% stayed overweight, 19% and 13% became obese, 0.7% and 0.1% became severely obese, and 44% and 34% became healthy weight. Among those obese at baseline, only 5% of the children and 4% of the adolescents decreased to healthy BMI, and 39% and 31% went from obese to overweight. Forty-five percent of children and 55% of adolescents remained obese. Forty percent of children and 24% of adolescents, respectively, decreased from severely obese to obese over follow-up. In general, the majority of children who lost weight shifted to next lowest BMI category. Specifically, among those who were overweight at baseline, 92% shifted to high healthy weight and 8% to low healthy weight. Among those who were obese at baseline, 76% shifted to overweight, 22% to high healthy, and 2% to low healthy weight. Among those in the severely obese category at baseline, 82% shifted to obese, 12% to overweight, 5% to high healthy weight, and 2% to low healthy weight (data not shown).

There was a strong association between change in BMI category and change in BP across BMI categories in both age groups and genders (Table 5). After we adjusted for race, insurance type, year of cohort entry (secular trend), study site, annual visit rate, and baseline SBP percentile, small but significant decreases in SBP and DBP percentiles were observed for those whose weight stayed normal in both age groups and gender. In girls and boys 3 to 11 years old, both SBP and DBP percentiles increased significantly when BMI increased from normal to either overweight or obese and when it increased from overweight to obese; the same patterns were observed in adolescents, but the

TABLE 4 Incident HTN, Change in BMI and BP Across Measured Visits Relative to Baseline BMI Category in Children Ages 3–11 y

	N Incident HTN	*N*	Change in SBP Mean (SE)	*P* for Difference Baseline to Follow-up	Change in DBP Mean (SE)	*P* for Difference Baseline to Follow-up
Healthy wt						
Stayed healthy wt	38	27 888	−3.7 (0.2)	<.0001	−5.6 (0.2)	<.0001
Healthy wt to overweight	14	6785	3.6 (0.4)	<.0001	−2.3 (0.4)	<.0001
Healthy wt to obese	1	91	9.8 (0.5)	<.0001	2.0 (0.4)	.0006
Healthy wt to severely obese	1	23	18.9 (0.9)	<.0001	7.4 (0.8)	<.0001
Overweight						
Stayed overweight	5	2907	−1.8 (0.5)	.0399	−4.2 (0.4)	<.0001
Overweight to healthy wt	7	3535	−9.1 (0.4)	<.0001	−7.6 (0.3)	<.0001
Overweight to obese	8	1514	4.3 (0.5)	<.0001	0.0 (0.5)	.9851
Overweight to severely obese	0	53	13.5 (1.0)	<.0001	5.5 (0.9)	<.0001
Obese						
Stayed obese	17	3383	−1.8 (0.6)	.1574	−2.3 (0.5)	.0014
Obese to healthy wt	1	357	−15.3 (0.4)	<.0001	−9.9 (0.4)	<.0001
Obese to overweight	14	2943	−8.1 (0.5)	<.0001	−6.6 (0.5)	<.0001
Obese to severely obese	15	914	7.3 (1.0)	<.0001	3.1 (0.9)	.0014
Severely obese						
Stayed severely obese	19	1214	1.8 (1.1)	.9951	−2.1 (1.0)	.9017
Severe obese to healthy wt	0	47	−20.8 (0.7)	<.0001	−15.2 (0.6)	<.0001
Severe obese to overweight	0	51	−13.5 (0.7)	<.0001	−11.8 (0.7)	<.0001
Severely obese to obese	15	857	−7.4 (0.8)	<.0001	−7.6 (0.7)	<.0001

Models adjusted for gender, race, insurance type, year of cohort entry (secular trend), study site, annual visit rate, and baseline SBP percentile.

TABLE 5 Incident HTN, Change in BMI and BP Across Measured Visits Relative to Baseline BMI Category in Adolescents Ages 12–17 y

	N Incident HTN	*N*	Change in SBP	*P* for Difference Baseline to Follow-up	Change in DBP	*P* for Difference Baseline to Follow-up
Healthy wt						
Stayed healthy wt	27	15 526	−4.0 (0.4)	<.0001	−2.8 (0.4)	<.0001
Healthy wt to overweight	11	2257	5.1 (0.7)	<.0001	2.0 (0.6)	.1927
Healthy wt to obese	0	19	12.8 (0.9)	<.0001	7.5 (0.8)	<.0001
Healthy wt to severely obese	0	5	20.8 (1.6)	<.0001	14.5 (1.4)	<.0001
Overweight						
Stayed overweight	7	2592	−3.4 (0.8)	.0086	−1.9 (0.7)	.587
Overweight to healthy wt	4	1705	−12.5 (0.6)	<.0001	−6.7 (0.5)	<.0001
Overweight to obese	7	658	4.3 (1.0)	<.0001	3.6 (0.8)	.0024
Overweight to severely obese	0	6	12.3 (1.7)	.0018	10.7 (1.4)	<.0001
Obese						
Stayed obese	31	2458	−5.3 (1.0)	<.0001	−2.1 (0.9)	.7508
Obese to healthy wt	0	185	−22.1 (0.6)	<.0001	−12.3 (0.6)	<.0001
Obese to overweight	9	1386	−13.0 (0.9)	.9968	−7.5 (0.8)	<.0001
Obese to severely obese	7	444	2.7 (1.7)	<.0001	5.0 (1.5)	.0926
Severely obese						
Stayed severely obese	25	733	−6.1 (2.0)	.2357	−3.6 (1.7)	.9113
Severe obese to healthy wt	0	23	−30.9 (1.2)	<.0001	−20.9 (1.0)	<.0001
Severe obese to overweight	0	19	−21.8 (1.3)	<.0001	−16.1 (1.2)	<.0001
Severely obese to obese	4	251	−14.1 (1.4)	<.0001	−10.7 (1.2)	<.0001

Models adjusted for gender, race, insurance type, year of cohort entry (secular trend), study site, annual visit rate, and baseline SBP percentile.

changes were greater, with the greatest increases seen in SBP percentile in girls 12 to 17 years old. Those who stayed overweight, obese, or severely obese also had small, not statistically significant decreases in SBP and DBP percentiles. Children and adolescents who decreased from obese to healthy weight or overweight to healthy weight had significant changes in SBP and DBP percentiles, as did those who decreased from severely obese to obese, overweight, or healthy weight. Children and adolescents whose weight increased to overweight, obese, or severely obese had statistically significant increases in SBP and DBP percentiles. There were no statistically significant differences in annual visit rate between BMI change categories.

Change in BMI and Risk of Incident HTN

Hazard ratios for the association between change in BMI and incident HTN and adjusted for gender, race, insurance type, year of cohort entry (secular trend), study site, annual visit rate, and baseline SBP percentile are shown in Table 6. Similar to the changes seen with SBP, the risk for development of HTN was greatest among children and adolescents who stayed obese (HRs = 3.71 and 3.64, respectively). The risk of developing HTN was more than doubled in adolescents who went from healthy weight to overweight (HR = 3.06; 95% CI, 1.42–6.59) and children who went from overweight to obese (HR = 5.15; 95% CI, 2.24–11.86). Even children and adolescents who went from obese to overweight remained at higher risk for incident HTN (HRs = 1.79 and 1.46, respectively).

DISCUSSION

In this large retrospective cohort study of >100 000 children (age 3–11 years) and adolescents (age 12–17 years), we observed a strong association between change in BMI and change in BP over a short period of time. Few children or adolescents with normal BMI changed BMI categories over a median of 3.1 years, and a very small number became obese. Only a small number in the obese BMI category had a significant weight reduction, with ~4% decreasing to normal BMI. Significant increases in BP were seen in patients who remained overweight or obese or increased to overweight or obese, but the increase in development of HTN was seen only in relation to obesity.

These patterns in BMI over time are highly relevant. Even over this short period of growth, there were strong, positive associations for both baseline BMI and changes in BMI with change in BP percentiles among all age–gender groups. Remaining overweight or obese or an increase in BMI percentile into the overweight or obese categories resulted in significantly higher BP percentiles. This finding is consistent with previous studies showing a strong, positive association between BMI and blood pressure[11,21–23] and a recent meta-analysis showing that obese and overweight children have higher SBP and DBP compared with healthy weight children age 5 to 15 years.[16,24] In general, children and adolescents had similar trends in changes in BP

TABLE 6 HR and 95% CIs[a] in the Association of Change in BMI Category[b] and Development of Incident HTN

BMI Category[b]	Children 3–11 y				Adolescents 12–17 y			
	N Incident HTN	Person-Years	HR	95% CI	*N* Incident HTN	Person-Years	HR	95% CI
Stayed healthy wt	38	70 361	1.00	Reference category	27	29 781	1.00	Reference category
Healthy wt to overweight or obese	16	18 963	1.14	0.63–2.05	11	5310	1.74	0.86–3.51
Stayed overweight	5	6452	1.09	0.43–2.79	7	4262	1.2	0.52–2.77
Obese or overweight to healthy wt	8	10 368	1.09	0.51–2.34	4	4242	0.71	0.25–2.04
Overweight to obese or severely obese	8	4014	2.25	1.05–4.84	7	1384	3.39	1.47–7.82
Stayed obese	66	15 109	3.71	2.43–5.67	67	7026	3.64	2.27–5.82
Obese to overweight	14	8063	1.79	0.96–3.33	9	517	1.46	0.68–3.12

[a] Adjusted for gender, race, insurance type, year of cohort entry (secular trend), study site, annual visit rate, and baseline SBP percentile.

[b] BMI categories: Low healthy wt, 5th–49th percentile; high healthy wt, 50th–84th percentile; overweight, 85th–94th percentile; obese, 95th–99th percentile; severely obese, ≥99th percentile.

percentiles within each BMI change category. However, adolescents with BMI increases had significantly larger increases in BP percentiles. In addition, the association between change in BMI category and incident HTN, defined as having ≥3 BPs at or above the 95th percentile at consecutive clinic visits, followed the pattern seen in the association of the change in BMI with change in BP.

We divided the normal BMI groups (5th–84th percentile BMI) into high and low normal BMI and did not observe a significant difference in the relationship between these BMI categories with either mean BP percentile or incident HTN. Thus, this study clearly shows the benefit of all levels of normal BMI, consistent with other studies that found minimal risk of HTN within the overall range of normal BMI.[22] Furthermore, this study clearly shows the adverse effect of obesity levels of BMI on incident HTN in children and adolescents, especially those who remained obese.

In this cohort 54% of children and adolescents maintained a healthy weight, but shifts in BMI category over the years of follow-up were common. Of the total cohort, 11% became overweight, 3% became obese, and 2% became severely obese, while 27% shifted to a lower BMI category. These percentages are highly relevant because the largest increases in BP percentile occurred in association with weight gain or with maintenance of overweight or obese BMI percentiles. Even obese children and adolescents who lost weight by shifting to overweight or healthy weight had modest increases in SBP percentile; these patterns are consistent with others in the literature.[12,23] Of particular interest, a small percentage of obese and severely obese children and adolescents had a reduction in BMI to the healthy weight category. Because this study relied on a retrospective EHR review, we do not have data that might explain this change, other than there were no significant differences in the annual visit rate among the weight change categories.

There are some potential limitations to this study. First, inclusion in the study population required that a child have 3 separate clinic BP measurements during the observation period. Therefore, not all children and adolescents were included; however, the study represents 100 000 of around 200 000 having clinic visits and 80 000 with 2 to 4 years of continuous enrollment in the health plans. The criterion for HTN requiring 3 separate visits also introduces the possibility that children with more clinic visits will be identified as hypertensive, simply because they have had more BP measurements. To examine this possibility, we conducted a sensitivity analysis, that is, changing the inclusion criteria to ≥2 visits and identified only 8 additional cases of HTN. Thus, in this study it appears that a diagnosis of HTN required a persistent BP elevation over 3 clinic visits.

In addition, a sensitivity analysis showed that changing the inclusion criteria to ≥2 visits did not change the rate of incident HTN. Second, these findings may not be generalizable to other patient populations or care delivery systems. Nevertheless, the study population includes substantial diversity in race and ethnicity.[24] In addition, in our study population 16% were overweight and 16% were obese, which is similar to the prevalence of overweight (15%) and obesity (17%) recently reported in the National Health and Nutrition Examination Survey.[1,25] Third, some have questioned the accuracy of BP, height, and weight measurements obtained in the course of routine clinical care.[25] Clinic nurses at all study sites were trained in proper BP, height, and weight measurement techniques for children and adolescents, and data review procedures were implemented to identify and exclude the small number of inconsistent or clinically implausible measures, especially for height. Thus, these data reflect the reality of the clinical setting and the information at hand when clinicians are faced with making decisions about care. Finally, the study did not search for comorbid conditions that might influence levels of BP, other than, in general, excluding patients with recent significant weight loss. For instance, BP can be effected by diabetes, renal disease, inflammatory diseases, exceptionally poor levels of fitness, or smoking. Nevertheless, we believe the overall size of this study and low prevalence of these factors in this age group substantially reduce the likelihood of their altering these results.

CONCLUSIONS

In this large cohort study of >100 000 children and adolescents, a strong positive association was observed between increase in BMI and both increase in BP percentile and risk of developing HTN. Obesity, especially severe obesity, at a young age confers an increased risk of early onset of cardiometabolic diseases such as HTN. The significant adverse effect of weight gain and obesity early in life, and over a short period of time, emphasizes the importance of developing early and effective clinical and public health strategies directed at the primary prevention of overweight and obesity.

ACKNOWLEDGMENT

Dr Parker had full access to all data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

ABBREVIATIONS

BP: blood pressure
CI: confidence interval
DBP: diastolic blood pressure
EHR: electronic health records
HR: hazard ratio
HTN: hypertension
SBP: systolic blood pressure

Accepted for publication Dec 17, 2015

Address correspondence to Emily D. Parker, PhD, MPH, Research Investigator, HealthPartners Institute for Education and Research, Mail Stop 23301A, 3311 Old Shakopee Rd East, Bloomington, MN 55425. E-mail: emily.d.parker@healthpartners.com

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: Funded by the National Heart, Lung, and Blood Institute at the National Institutes of Health, R01 HL093345, "Childhood Hypertension and Obesity: Diagnosis, Care, and Costs" study to HealthPartners Institute for Education and Research (principal investigator Patrick O'Connor). Funded by the National Institutes of Health (NIH).

POTENTIAL CONFLICT OF INTEREST: Dr Lo has received research funding from Sanofi unrelated to the current study; the other authors have indicated they have no potential conflicts of interest to disclose.

REFERENCES

1. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA*. 2014;311(8):806–814
2. Falkner B. Hypertension in children and adolescents: epidemiology and natural history. *Pediatr Nephrol*. 2010;25(7):1219–1224
3. Flynn J. The changing face of pediatric hypertension in the era of the childhood obesity epidemic. *Pediatr Nephrol*. 2013;28(7):1059–1066
4. Lo JC, Sinaiko A, Chandra M, et al. Prehypertension and hypertension in community-based pediatric practice. *Pediatrics*. 2013;131(2). Available at: www.pediatrics.org/cgi/content/full/131/2/e415
5. Daley MF, Sinaiko AR, Reifler LM, et al. Patterns of care and persistence after incident elevated blood pressure. *Pediatrics*. 2013;132(2). Available at: www.pediatrics.org/cgi/content/full/132/2/e349
6. Koebnick C, Black MH, Wu J, et al. High blood pressure in overweight and obese youth: implications for screening. *J Clin Hypertens (Greenwich)*. 2013;15(11):793–805
7. Chen X, Wang Y. Tracking of blood pressure from childhood to adulthood: a systematic review and meta-regression analysis. *Circulation*. 2008;117(25):3171–3180
8. Juhola J, Magnussen CG, Viikari JS, et al. Tracking of serum lipid levels, blood pressure, and body mass index from childhood to adulthood: the Cardiovascular Risk in Young Finns Study. *J Pediatr*. 2011;159(4):584–590
9. Vos LE, Oren A, Uiterwaal C, Gorissen WH, Grobbee DE, Bots ML. Adolescent blood pressure and blood pressure tracking into young adulthood are related to subclinical atherosclerosis: the Atherosclerosis Risk in Young Adults (ARYA) study. *Am J Hypertens*. 2003;16(7):549–555
10. Mamun AA, Lawlor DA, O'Callaghan MJ, Williams GM, Najman JM. Effect of body mass index changes between ages 5 and 14 on blood pressure at age 14: findings from a birth cohort study. *Hypertension*. 2005;45(6):1083–1087
11. Ostchega Y, Carroll M, Prineas RJ, McDowell MA, Louis T, Tilert T. Trends of elevated blood pressure among children and adolescents: data from the National Health and Nutrition Examination Survey 1988–2006. *Am J Hypertens*. 2009;22(1):59–67

12. Suglia SF, Clark CJ, Gary-Webb TL. Adolescent obesity, change in weight status, and hypertension: racial/ethnic variations. *Hypertension*. 2013;61(2):290–295

13. Jago R, Mendoza JA, Chen T, Baranowski T. Longitudinal associations between BMI, waist circumference, and cardiometabolic risk in US youth: monitoring implications. *Obesity (Silver Spring)*. 2013;21(3):E271–E279

14. Luepker RV, Jacobs DR, Prineas RJ, Sinaiko AR. Secular trends of blood pressure and body size in a multi-ethnic adolescent population: 1986 to 1996. *J Pediatr*. 1999;134(6):668–674

15. Muntner P, He J, Cutler JA, Wildman RP, Whelton PK. Trends in blood pressure among children and adolescents. *JAMA*. 2004;291(17):2107–2113

16. Friedemann C, Heneghan C, Mahtani K, Thompson M, Perera R, Ward AM. Cardiovascular disease risk in healthy children and its association with body mass index: systematic review and meta-analysis. *BMJ*. 2012;345:e4759

17. Ross TR, Ng D, Brown JS, et al The HMO Research Network Virtual Data Warehouse: a public data model to support collaboration. *eGEMs*. 2014;2(1):Article 2

18. Kuczmarski RJ, Ogden CL, Guo SS, et al 2000 CDC growth charts for the United States: methods and development. *Vital Health Stat 11*. 2002(246):1–190

19. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. *Pediatrics*. 2004;114(2 suppl 4th report):555–576

20. Allison PD. *Fixed Effects Regression Methods for Longitudinal Data Using SAS*. Cary, NC: SAS Institute, Inc; 2005

21. Falkner B, Gidding SS, Ramirez-Garnica G, Wiltrout SA, West D, Rappaport EB. The relationship of body mass index and blood pressure in primary care pediatric patients. *J Pediatr*. 2006;148(2):195–200

22. Tu W, Eckert GJ, DiMeglio LA, Yu Z, Jung J, Pratt JH. Intensified effect of adiposity on blood pressure in overweight and obese children. *Hypertension*. 2011;58(5):818–824

23. Marcus MD, Foster GD, El Ghormli L, et al. Shifts in BMI category and associated cardiometabolic risk: prospective results from HEALTHY study. *Pediatrics*. 2012;129(4). Available at: www.pediatrics.org/cgi/content/full/129/4/e983

24. Chorin E, Hassidim A, Hartal M, et al. Trends in adolescents obesity and the association between BMI and blood pressure: a cross-sectional study in 714,922 healthy teenagers. *Am J Hypertens*. 2015;28(9):1157–1163

25. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of obesity and trends in body mass index among US children and adolescents, 1999–2010. *JAMA*. 2012;307(5):483–490

Change in Weight Status and Development of Hypertension

Emily D. Parker, Alan R. Sinaiko, Elyse O. Kharbanda, Karen L. Margolis, Matt F. Daley, Nicole K. Trower, Nancy E. Sherwood, Louise C. Greenspan, Joan C. Lo, David J. Magid and Patrick J. O'Connor

Pediatrics 2016;137;
DOI: 10.1542/peds.2015-1662 originally published online February 19, 2016;

PEDIATRICS
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Change in Weight Status and Development of Hypertension

Emily D. Parker, Alan R. Sinaiko, Elyse O. Kharbanda, Karen L. Margolis, Matt F. Daley, Nicole K. Trower, Nancy E. Sherwood, Louise C. Greenspan, Joan C. Lo, David J. Magid and Patrick J. O'Connor

Pediatrics 2016;137;
DOI: 10.1542/peds.2015-1662 originally published online February 19, 2016;