ORIGINAL ARTICLE

Trends in Adolescents Obesity and the Association between BMI and Blood Pressure: A Cross-Sectional Study in 714,922 Healthy Teenagers

Ehud Chorin,[1,*] Ayal Hassidim,[2,*] Michael Hartal,[2,3] Ofer Havakuk,[1] Nir Flint,[1] Tomer Ziv-Baran,[4] and Yaron Arbel[1]

BACKGROUND
Seventeen percent of youth in the United States are obese. Obesity has been linked to higher prevalence of hypertension. Past studies were limited by their size and conflicting results. The aim of this study was to analyze trends in adolescents' obesity between 1998 and 2011 and to evaluate the relationship between blood pressure and body mass index (BMI) in healthy adolescents.

METHODS
All adolescents who underwent a medical exam in the years 1998–2011 and were found fit for combat duties in the Israeli Defense Force were included.

RESULTS
The cohort included 714,922 healthy adolescents with 59% of them being males. The mean age was 17.4±0.45 and mean BMI was 22±3.5 kg/m^2. The percentage of overweight adolescents (BMI > 25 kg/m^2) has increased from 13.2% in 1998 to 21% in 2011, $P < 0.001$. The mean systolic and diastolic blood pressures increased with increasing BMI deciles (systolic blood pressure by 10 mm Hg and diastolic blood pressure by 3–4 mm Hg from the 1st decile to the 10th decile, $P < 0.001$ for both). In multivariate analysis, each increase of 1 unit of BMI was associated with an increased risk of systolic blood pressure above 130 mm Hg in both males (OR = 1.108, 95% CI 1.107–1.110, $P < 0.001$) and females (OR = 1.114, 95% CI 1.139–1.146, $P < 0.001$).

CONCLUSIONS
BMI in adolescents is significantly associated with systolic blood pressure and diastolic blood pressure in both genders and in both the normal weight and overweight groups. There has been consistent trend of increasing BMI values over recent years.

Keywords: army recruitment; BMI; blood pressure; conscripts; gender; hypertension; Israel; obesity; teenagers; trends.

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Obesity is an important risk factor for cardiovascular disease (CVD) in adults. Children and adolescents who are obese are likely to be obese as adults[1] and are therefore at higher risk for adult health problems such as heart disease, type 2 diabetes mellitus, stroke, several types of cancer, and osteoarthritis.[2]

In 2011–2012, 16.9% (95% CI, 14.9–19.2%) of 2–19-year-olds in the United States were obese. Overall, there was no significant change in obesity prevalence from 2003–2004 to 2011–2012 in 2–19-year-olds in the United States.[3]

An association between hypertension and obesity in adolescents has been established, and even among nonobese adolescents, increased prevalence of hypertension has been reported with increasing weight.[4–6] Nevertheless, some of these studies were relatively small and therefore limited in detecting a true relationship between blood pressure and body mass index (BMI). Interpreting the blood pressure–BMI relationship is further complicated by the suggestion from some studies of a threshold effect below which there appears to be no correlation between the variables.[7]

We hypothesized that BMI was associated with increased systolic blood pressure (SBP), diastolic blood pressure (DBP), and pulse pressure.

The aim of our study was to analyze trends in adolescents' obesity between 1998 and 2011 and to evaluate the relationship of SBP and DBP with BMI in the largest cohort to date of healthy teenagers.

METHODS

Source of data

As a part of the army recruitment process, most Israeli adolescents undergo a routine medical examination and classification. Excluded are some minority populations such

Correspondence: Yaron Arbel (yaronarbel@gmail.com).

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[1]Department of Cardiology, Tel Aviv Sourasky Medical Center, Tel Aviv University, Tel Aviv, Israel; [2]Israel Defense Forces Medical Corps, Israel; [3]The Department of Military Medicine, The Hebrew University of Jerusalem, Jerusalem, Israel; [4]Department of Epidemiology and Preventive Medicine, School of Public Health, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel.

***These authors contributed equally to this work.**

as Israeli-Arabs and ultra religious Jews. The medical evaluation includes a questionnaire filled out by the recruit and his family physician, a physical examination that includes: anthropometric measurements, blood pressure measurements, a medical examination by a physician, and further tests and consultations as needed. Blood pressure was measured with the participant in a seated position following 5 minutes of quiet rest. There is one blood pressure measurement for each individual. The measurement was conducted by trained technicians. Quality control for the blood pressure measurements included retraining if necessary and monitoring of equipment and equipment repair. The products of this process are numerical codes indicative of medical diagnosis and functional status. The data are stored in a central database. The data in our study were retrieved from this database with the approval of the Israel Defense Forces Institutional Review Board, while maintaining strict subject anonymity.

Study population

The study population included all Israeli adolescents examined during the years 1998–2011. We excluded subjects that were younger than 16 years or subjects older than 20 years at the time of medical assessment. Next, we excluded subjects that did not have blood pressure, weight, or height measurements recorded in the database. Measurements were available for 714,922 study participants, in whom the BMI could be calculated. In order to avoid bias due to various background diseases and medications, we included only those subjects found to be fit for combat duties, resulting in a homogenous healthy adolescent population. Our final study population was comprised of 714,922 healthy individuals who did not take any chronic medications, had no known underlying medical condition and were found fit to conduct vigorous physical activity. The study population included 422,213 males (59%) and 292,709 females (41%).

BMI groups

Height and weight were measured by a trained medical technician. Height was measured with shoes off. Weight was measured with undergarments or only light clothes on, with shoes off, and was rounded to the nearest kilogram. BMI was calculated as weight in kilograms divided by the square height in meters. BMI values were categorized into deciles for analysis.

Socioeconomic status

Socioeconomic status data were based on a ranking system by the Israeli Central Bureau of Statistics, which ranks all the cities, towns, and villages on a composite scale of 1 (lowest) to 10 (highest). Data regarding place of residence were obtained from records of the Israeli Ministry of Interior. The socioeconomic status is calculated based on this parameters: percent of families with at least 4 children; ratio of individuals age 0–19 and 65+ years (dependent population), to 20–64-year-olds (workforce); median age; percent of undergraduate students among all 20–29-year-olds; percent of 18-year-olds that are entitled to a high school diploma; percent of car and truck owners; percent of new cars and trucks; average income per capita; percent of work seekers that are at least 15 years old; percent of subminimum wage earners; percent of wage earners twice the average income; percent of unemployment compensation recipients; percent of income support recipients; percent of recipients of income supplement from recipients of regular old-age pension.

Statistical analysis

All data were summarized and displayed as mean (± standard deviation) for continuous variables and as count (percentage) of patients in each group for categorical variables. Categorical variables were compared using Chi-square tests and continuous variables were compared using the independent sample *t* test or analysis of variance (Scheffee's procedure was used for post hoc multiple comparison).

Univariate and multivariate logistic regression models were used to evaluate the influence of BMI on high resting SBP (above 130 mm Hg) and high resting DBP (above 85 mm Hg). These cutoff values were selected since they fulfill the high blood pressure criteria for metabolic syndrome according to the ATP III report. We adjusted our regression models for age, gender, and socioeconomic status. We used an interaction variable in order to evaluate if the relationship between BMI and high resting SBP or high resting DBP differed between males and females. We calculated the probability of having high resting SBP for a given BMI in all study populations and demonstrate it with a scatter plot.

A 2-tailed $P < 0.05$ was considered statistically significant. All analyses were performed with the SPSS 21.0 software (SPSS, Chicago, IL).

RESULTS

Subject characteristics

The cohort included 714,922 apparently healthy predrafted teenagers enlisted as fit for combat duties. Mean subject age was 17.4 ± 0.45 with 59% being male. Anthropometric variables of the study population are listed in Tables 1 and 2.

SBP, DBP, pulse pressure, and BMI

Male participants were taller and heavier (174.1 ± 6.7 cent' and 67 ± 12 kg vs. 162.6 ± 6 cent' and 58.4 ± 9.7 kg in females $P < 0.001$ for all). The BMI was clinically similar though statistically significant between male and female subjects (22 ± 3.5 kg/m^2 in the male participants and 22 ± 3.4 kg/m^2 in the female participants, $P = 0.001$). In males, mean SBP has increased along the increasing BMI deciles (from 115 ± 11.1 mm Hg in the 1st decile to 123.9 ± 10.9 mm Hg in the 10th decile, P for trend < 0.001) and mean DBP has increased along with increasing BMI deciles (from 70.4 ± 8.1 mm Hg in the 1st decile to 73.4 ± 8.1 mm Hg in the 10th decile, P for trend < 0.001). Similar results were seen in the female subjects (with SBP increasing from 107.5 ± 10.8 mm Hg in the 1st decile to 116.7 ± 11.4 mm Hg in the 10th decile P for trend < 0.001 and DBP increasing from 68.5 ± 7.9 mm Hg in the

1st decile to 72.4 ± 8 mm Hg in the 10th decile P for trend < 0.001) (Figure 1 A, B, Figure 2A, B; Table 2).

In males, mean pulse pressure increased with BMI, from 44.6 ± 10.2 mm Hg in the 1st decile to 50.5 ± 11.7 mm Hg in the 10th decile (P for trend < 0.001). Comparable results were seen in female subjects, with pulse pressure increasing from 39 ± 8.8 mm Hg in the 1st decile to 44.5 ± 10.1 mm Hg in the 10th decile (P for trend < 0.001) (Table 3). We could not find a threshold where the association becomes significant as can be seen in the graphs and tables.

Obesity trends 1998–2011

There was a significant trend from 1998 through 2011 in mean BMI values in both genders. In males, mean BMI has increased along the years (from 21.6 ± 3.3 kg/m^2 in 1998 to 22.46 ± 3.77 kg/m^2 in 2011, P for trend < 0.001). Similar results were seen in female subjects, mean BMI increased from 21.6 ± 3.3 kg/m^2 in 1998 to 22.83 ± 3.44 kg/m^2 in 2011, P for trend < 0.001) (Figure 3A). The overweight (BMI > 25) percentage has increased from 13.2% in 1998 to 21% in 2011, P for trend < 0.001 (Figure 3B).

Logistic regression models

There was significant interaction (P < 0.001) between BMI and gender; therefore we analyzed the influence of BMI deciles on hypertension separately for males and for females. Multivariate logistic regression models were used to evaluate the predictors of high resting SBP (above 130 mm Hg) and high resting DBP (above 85 mm Hg) while controlling for socioeconomic status and the age of the subjects. Higher

Table 1. Distribution (mean ± SD) of anthropometric data, BP measurements, SES, and BMI among males

Deciles of BMI	Mean BMI (range) (kg/m²)	Number of valid subjects	Weight (kg)	Height (Cent')	Systolic blood pressure (mm Hg)	Diastolic blood pressure (mm Hg)	Pulse pressure (mm Hg)	SES
1.	17.5 ± 0.6 (16.0–18.2)	42,268	53 ± 4.4	174.1 ± 6.6	115 ± 11.1	70.4 ± 8.1	44.6 ± 10.3	5.8 ± 1.6
2.	18.7.6 ± 0.2 (18.3–19.2)	41,962	56.7 ± 4.5	174.1 ± 6.7	116.2 ± 11.1	70.6 ± 8.1	45.6 ± 10.7	5.8 ± 1.6
3.	19.6 ± 0.2 (19.3–20)	42,514	59.4 ± 4.7	174.2 ± 6.8	117 ± 11.1	70.6 ± 8.1	46.4 ± 10.9	5.8 ± 1.6
4.	20.3 ± 0.2 (20–20.6)	41,814	61.4 ± 4.9	174 ± 6.8	117.5 ± 11.1	70.7 ± 8.1	46.8 ± 11.1	5.8 ± 1.6
5.	21 ± 0.2 (20.6–21.3)	41,926	63.5 ± 4.9	174 ± 6.5	118.2 ± 11	70.8 ± 8.0	47.3 ± 11.2	5.8 ± 1.6
6.	21.7 ± 0.2 (21.3–22.1)	42,703	66 ± 5.2	174.2 ± 6.8	118.8 ± 11	71 ± 8.1	47.8 ± 11.4	5.8 ± 1.6
7.	22.6 ± 0.3 (22.1–23)	42,703	68.4 ± 5.3	174 ± 6.7	119.6 ± 11	71.1 ± 8.1	48.4 ± 11.6	5.8 ± 1.6
8.	23.7 ± 0.4 (23–24.4)	41,891	72 ± 5.7	174.2 ± 6.8	120.2 ± 10.9	71.4 ± 8.1	48.8 ± 11.7	5.7 ± 1.6
9.	25.4 ± 0.7 (24.4–26.7)	42,273	77.3 ± 6.3	174.2 ± 6.8	121.4 ± 10.9	71.9 ± 8.1	49.5 ± 11.8	5.7 ± 1.6
10.	29.6 ± 2.3 (26.7–36)	42,159	90.2 ± 10.1	174.4 ± 6.8	123.9 ± 10.9	73.4 ± 8.1	50.5 ± 11.7	5.6 ± 1.6

Abbreviations: BMI, body mass index; SES, socioeconomic status.

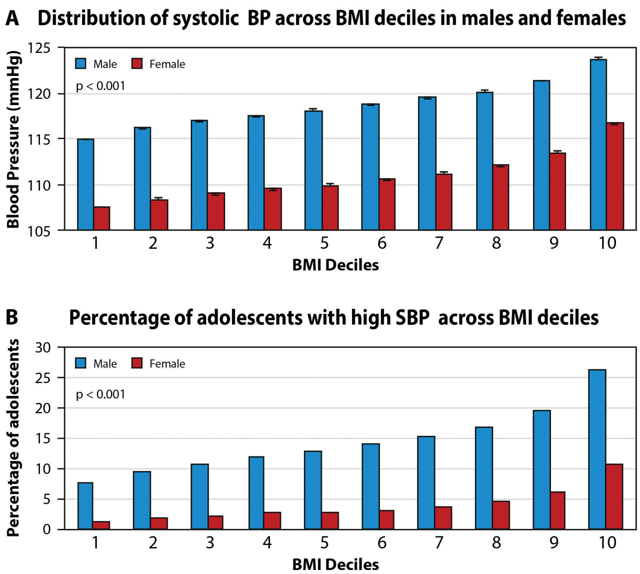

Figure 1. (**A**) Distribution of SBP across BMI deciles in males and females. (**B**) Percentage of adolescents with SBP above 130 mm Hg across BMI deciles. Abbreviations: BMI, body mass index; BP, blood pressure; SBP, systolic blood pressure.

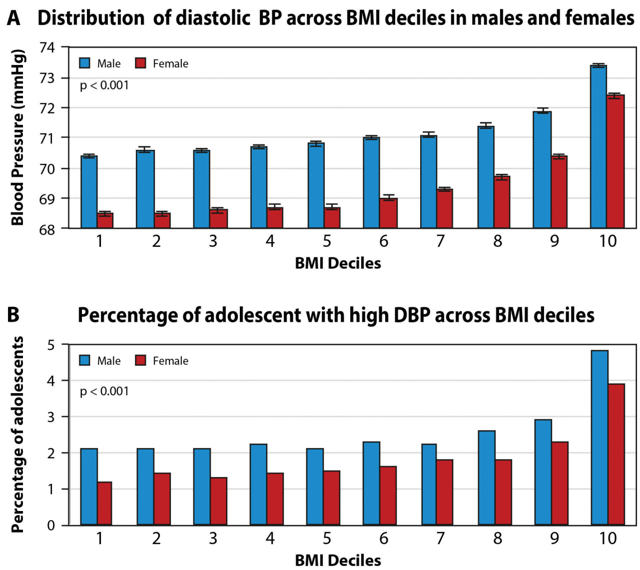

Figure 2. (**A**) Distribution of DBP across BMI deciles in males and females. (**B**) Percentage of adolescents with DBP above 85 mm Hg across BMI deciles. Abbreviations: BMI, body mass index; BP, blood pressure; DBP, diastolic blood pressure.

Table 2. Distribution (mean ± SD) of anthropometric data, BP measurements, SES, and BMI among females

Deciles of BMI	Mean BMI (range) (kg/m²)	Number of valid subjects	Weight (kg)	Height (Cent')	Systolic blood pressure (mm Hg)	Diastolic blood pressure (mm Hg)	Pulse pressure (mm Hg)	SES
1.	17.6 ± 0.6 (16–18.4)	29,404	47.9 ± 3.7	164.6 ± 6	107.5 ± 10.8	68.5 ± 7.9	39 ± 8.8	6.1 ± 1.5
2.	18.9 ± 0.2 (18.4–19.3)	29,328	50.6 ± 3.6	163.5 ± 5.8	108.4 ± 10.9	68.5 ± 7.9	39.8 ± 9	6.1 ± 1.5
3.	19.6 ± 0.2 (19.3–20)	29,145	52.3 ± 3.7	163 ± 5.7	109 ± 10.9	68.6 ± 7.8	40.4 ± 9.1	6.1 ± 1.5
4.	20.3 ± 0.2 (20–20.7)	29,131	53.7 ± 4	162.5 ± 5.9	109.5 ± 11	68.7 ± 7.9	40.7 ± 9.2	6.1 ± 1.5
5.	21 ± 0.2 (20.7–21.3)	29,398	55.3 ± 4	162.2 ± 5.7	109.9 ± 11	68.7 ± 7.9	41.1 ± 9.3	6.1 ± 1.5
6.	21.7 ± 0.2 (21.3–22.1)	29,414	56.9 ± 4.3	161.8 ± 6	110.5 ± 10.9	69 ± 7.9	41.5 ± 9.3	6.1 ± 1.5
7.	22.6 ± 0.3 (22.1–23)	29,094	59.2 ± 4.5	161.8 ± 6.1	111.2 ± 10.9	69.3 ± 7.9	41.8 ± 9.5	6.1 ± 1.5
8.	23.6 ± 0.3 (23–24.3)	29,047	62 ± 4.8	161.9 ± 6.1	112.1 ± 11	69.7 ± 7.9	42.4 ± 9.6	6 ± 1.5
9.	25.2 ± 0.7 (24.3–26.5)	29,479	66.2 ± 5.2	161.9 ± 6	113.2 ± 11.2	70.4 ± 8	43.1 ± 9.8	5.9 ± 1.5
10.	29.2 ± 2.3 (26.5–36)	29,269	77.2 ± 8.7	162.2 ± 6.1	116.7 ± 11.4	72.4 ± 8	44.5 ± 10.1	5.8 ± 1.5

Abbreviations: BMI, body mass index; SES, socioeconomic status.

Table 3. Multivariate logistic regression model evaluating causes of SBP above 130 mm Hg

	Males	Females	
	OR (95% CI)	OR (95% CI)	*P* value between genders
1st BMI decile	1 (reference)	1 (reference)	
2nd BMI decile	1.25 (1.19–1.31, *P* < 0.001)	1.34 (1.18–1.52, *P* = 0.007)	0.228
3rd BMI decile	1.44 (1.38–1.51, *P* < 0.001)	1.62 (1.43–1.84, *P* < 0.001)	0.16
4th BMI decile	1.58 (1.51–1.66, *P* < 0.001)	1.92 (1.7–2.16, *P* < 0.001)	0.002
5th BMI decile	1.72 (1.66–1.8, *P* < 0.001)	2.09 (1.86–2.35, *P* < 0.001)	<0.001
6th BMI decile	1.92 (1.83–2, *P* < 0.001)	2.25 (2–2.53, *P* < 0.001)	0.002
7th BMI decile	2.16 (2.07–2.26, *P* < 0.001)	2.7 (2.41–3.03, *P* < 0.001)	<0.001
8th BMI decile	2.4 (2.30–2.51, *P* < 0.001)	3.32 (2.97–3.72, *P* < 0.001)	<0.001
9th BMI decile	2.89 (2.77–3.01, *P* < 0.001)	4.48 (4.02–4.99, *P* < 0.001)	<0.001
10th BMI decile	4.15 (3.97–4.32, *P* < 0.001)	8.14 (7.34–9.02, *P* < 0.001)	<0.001

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratio; SBP, systolic blood pressure.

BMI was independently associated with an increased risk of elevated blood pressure in a dose–response curve.

In multivariate analysis, each increase of 1 unit of BMI (measured continuously) was associated with an increased risk of SBP above 130 mm Hg (OR = 1.108, 95% CI 1.107–1.110, $P < 0.001$) in males. Similar results were found in females, (OR = 1.114, 95% CI 1.139–1.146, $P < 0.001$). Figure 4 A and B demonstrates the probability of having high resting SBP for a given BMI according to gender.

BMI was also associated with elevated DBP values in males (OR = 1.087, 95% CI 1.084–1.090, $P < 0.001$) and females (OR = 1.094, 95% CI 1.089–1.099, $P < 0.001$).

The 10th BMI deciles, in males, was associated with SBP above 130 mm Hg (OR = 4.15, 95% CI 3.97–4.32, $P < 0.001$) and DBP above 85 mm Hg (OR = 2.33, 95% CI 2.15–2.53, $P < 0.001$). In females, the 10th BMI was associated with SBP above 130 mm Hg (OR = 8.14, 95% CI 7.34–9.02, $P < 0.001$) and DBP above 85 mm Hg (OR = 3.27 95% CI 2.89–3.69, $P < 0.001$). Results of the multivariate analysis are shown in Table 4.

DISCUSSION

In this study, we evaluated the association between BMI and blood pressure in a serial cross-sectional study of 714,922 healthy adolescents. We have shown that BMI in adolescents (mean age, 17.4 years) is significantly associated with SBP and DBP in both genders. An important finding in our study is that BMI was positively associated with SBP and DBP in both the normal weight and overweight groups. In addition, we demonstrated a consistent trend of increasing BMI values over the years 1998–2011. Over this period, mean BMI increased by 1.0 kg/m² for men and 1.3 kg/m² for women.

Analyses of trends in obesity prevalence among adolescents have shown mixed results. Data from the Youth Risk Behavior Surveillance System, showed an increase in the prevalence of obesity between 1999 and 2011 but no change between 2009 and 2011.[8] Among public middle school students in New York City, a recent analysis in obesity found a decrease in obesity prevalence between 2006–2007 and 2010–2011.[9] Other researchers using a school-based survey

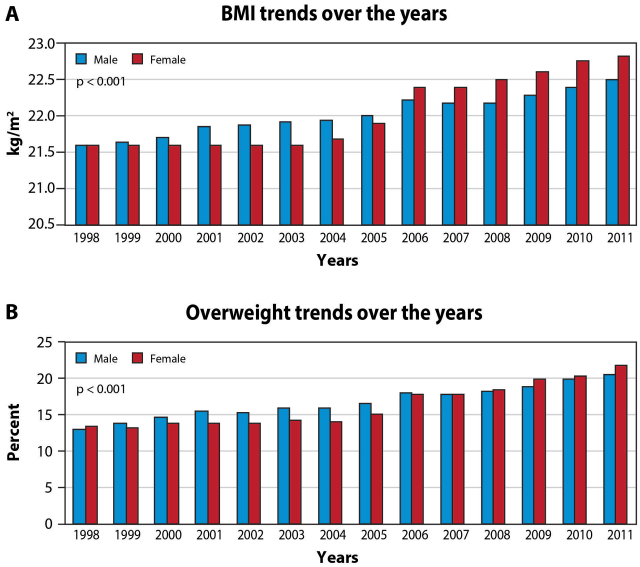

Figure 3. (**A**) BMI trend in males and females between 1998 and 2011. (**B**) Percentage of adolescents with overweight (BMI > 25 between 1998 and 2011. Abbreviations: BMI, body mass index.

found an increase in obesity prevalence among US adolescents between 2001–2002 and 2005–2006 but no change between 2005–2006 and 2009–2010.[10] Our results show a continuous increase in the prevalence of obesity in Israeli adolescents.

Obese youth are more likely to have risk factors for CVD, such as high cholesterol or high blood pressure. In a population-based sample of 5–17-year-olds, 70% of obese youth had at least one risk factor for CVD.[11] Children and adolescents who are obese are likely to be obese as adults[1] and are consequently more at risk for adult health problems such as heart disease, type 2 diabetes, stroke, numerous types of cancer, and osteoarthritis.[2] In 2012, more than one-third of children and adolescents in the United States were overweight or obese placing millions of children at risk for chronic illness, notably hypertension.[12]

The association between anthropometric values and blood pressure has been formerly investigated.[13,14] Even so, large sample sizes are required in order to make estimates with any degree of certainty. Furthermore, the effect of treatment in many populations truncates the distribution of blood pressures and therefore reduces the correlation that would be observed between BMI and blood pressure in untreated settings.

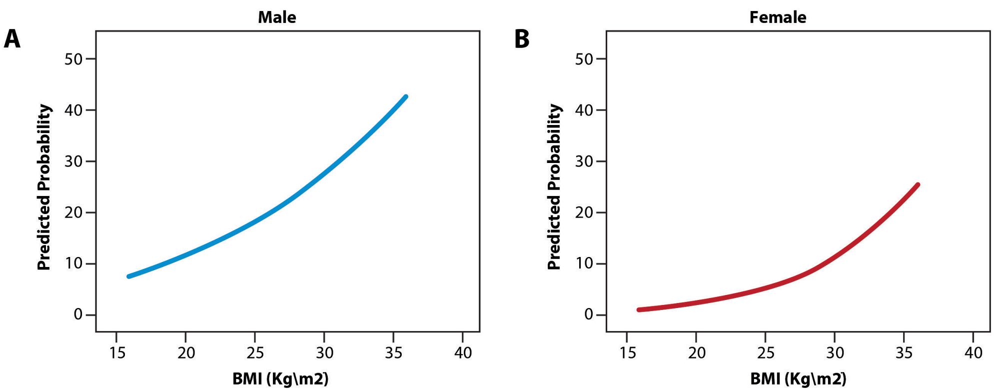

Figure 4. Probability of having high resting SBP for a given BMI according to gender.

Table 4. Multivariate logistic regression model evaluating causes of DBP above 85 mm Hg

	Males	Females	
	OR (CI)	OR (CI)	*P* value between genders
1st BMI decile	1 (reference)	1 (reference)	
2nd BMI decile	0.99 (0.90–1.09, *P* = 0.922)	1.19 (1.03–1.37, *P* = 0.018)	0.268
3rd BMI decile	1.00 (0.91–1.1, *P* = 0.862)	1.13 (0.98–1.31, *P* = 0.082)	0.091
4th BMI decile	1.05 (0.95–1.15, *P* = 0.320)	1.24 (1.081–1.44, *P* = 0.03)	0.086
5th BMI decile	1.03 (0.94–1.14, *P* = 0.455)	1.28 (1.11–1.47, *P* = 0.001)	0.031
6th BMI decile	1.09 (0.99–1.2, *P* = 0.058)	1.35(1.17–1.55, *P* < 0.001)	0.020
7th BMI decile	1.08 (0.98–1.12, *P* = 0.091)	1.54 (1.34–1.77, *P* < 0.001)	0.013
8th BMI decile	1.23 (1.12–1.35, *P* < 0.001)	1.57 (1.37–1.80, *P* = 0.001)	<0.001
9th BMI decile	1.41 (1.29–1.54, *P* < 0.001)	1.97 (1.72–2.24, *P* < 0.001)	<0.001
10th BMI decile	2.33 (2.15–2.53, *P* < 0.001)	3.27 (2.89–3.69, *P* < 0.001)	<0.001

Abbreviations: BMI, body mass index; CI, confidence interval; DBP, diastolic blood pressure.

Interpreting the blood pressure–BMI relationship is further complicated by the suggestion from some studies of a threshold effect below there appears to be no correlation between the variables.[15] Some of these studies have relatively small samples and therefore limited power to detect a true relationship. Even in larger studies, analyses were seldom conducted to evaluate the blood pressure–BMI association across the range of BMI values. Some authors have suggested that for women in unindustrialized settings there is no identifiable association between blood pressure and BMI, even at levels that would be considered obese (i.e., 30 kg/m^2).[16] In contrast, our study, with its cohort of more than 700,000 male and female adolescents, shows a near–linear association between BMI and blood pressure with no threshold effect. These data strongly suggest that overweight is a key determinant of elevated SBP and DBP in adolescents.

The mechanisms that contribute to elevated SBP in obese individuals are thought to be multifactorial. Most studies of children have focused on investigation of 3 main pathophysiological mechanisms: disturbances in autonomic function,[17,18] insulin resistance,[19] and abnormalities in vascular structure and function.[20] Obesity-induced hypertension is likely due to an overlap or combination of these factors. We demonstrated that both genders demonstrate an association between BMI and blood pressure. However, the association was more pronounced in females. The exact mechanism is not clear. However, it might be linked to hormonal factors that have an effect on endothelial function or the high incidence of polycystic ovaries in the highest decile.[21,22]

As mean BMI has increased since 1998, interventions and policies that can curb or reverse the increase, and mitigate the health effects of high BMI by targeting its metabolic mediators, are needed in most countries. With the growing prevalence of overweight and obese children in developed countries, there is a substantial need for more research describing the relationship between body habitus and blood pressure and the influence and efficacy of lifestyle programs designed to prevent the development of high blood pressure in overweight children. Our study has some limitations that need to be mentioned. First, we do not have a long-term morbidity and mortality follow up. Second, it is unclear whether an intervention focused on changes in diet might have different outcomes. In addition, we found an association between blood pressure and BMI. This association might not indicate causality. Finally, we do not have laboratory test data in our study population. Despite these limitations, this retrospective analysis provides valuable information that reflects contemporary, real-world practice.

Perspectives

Obesity in youth is a growing epidemic worldwide. It is imperative to assess trends in obesity and evaluate its toll on cardiovascular risk factors such as hypertension.

In our study, we evaluated the association between BMI and blood pressure in a serial cross-sectional study of 714,922 healthy adolescents. We have shown that BMI in adolescents is significantly associated with SBP and DBP in both genders and in both the normal weight and overweight groups. There has been consistent trend of increasing BMI values over recent years. With the growing prevalence of overweight and obesity in children, there is a need for further research describing the relationship between body habitus and cardiovascular risk factors and efficacy of interventions designed to prevent the development of high blood pressure in overweight children.

DISCLOSURE

The author (or authors) declared no conflict of interest.

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