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Percentile distribution of blood pressure readings in relation to body mass index: a population-based cross-sectional study ADOPOLNOR

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Abstract: Recent upward trends toward elevated blood pressure and increased weight expressed in terms of body mass index in children and adolescents call for regular monitoring of their physical growth and age-related changes in blood pressure. This requires adequate tools – reference values of a normal blood pressure range. The main objective of this study was to provide sex- and BMI-specific percentile reference values for systolic and diastolic blood pressure based on the adolescent Polish population, participants in the ADOPOLNOR study. A cross-sectional survey was carried out on a representative, randomly selected cohort of 4,941; 2,451 male and 2,490 female students aged 10–18 years, residents in Wielkopolska province and its capital, the city of Poznań. All examinations were performed in school nursery rooms during morning hours according to standard procedures. Body height and weight were measured and BMI was calculated. Blood pressure was measured twice on each occasion on the right arm using a fully calibrated TECH MED TM-Z mercury gauge sphygmomanometer with sets of exchangeable cuffs and a clinical stethoscope. The blood pressure classification was determined using the surveillance method. For each participant, the mean of measurements taken on each of the three occasions was calculated and served as his/her final blood pressure value. Using the LMS method, fitted percentile curves were created for BMI-related systolic and diastolic blood pressure. The findings revealed that age related blood pressure pattern was similar in boys and girls. It showed a steady increase of systolic and diastolic blood pressure with age. There was a positive correlation between the systolic and diastolic blood pressure indicating that when systolic blood pressure increased so diastolic did ($r=0.61$ at $p<0.01$). Boys were likely to have relatively higher mean values of systolic and diastolic blood pressure and steeper slope for BMI-related change in blood pressure than girls. Similar pattern was found for age-related changes in BMI. The quotation of 3rd, 5th, 10th, 15th, 25th, 50th, 75th, 85th, 90th, 95th, and 97th at any given BMI between 12 kg/m^2 and 35 kg/m^2 provided indication of the entire variation in blood pressure of adolescent males and females aged 10–18 years. The sex- and BMI-specific reference values and charts for systolic and diastolic blood pressure may be a useful

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tool in monitoring blood pressure for early detection of its abnormal level and treatment of children and adolescents with high blood pressure.

Key words:

Introduction

Blood pressure (BP) is a physiological trait defined as the pressure of the blood against the inner walls of the blood vessels, varying in different parts of the body during different phases of contraction of the heart and under different conditions of health, exertion, etc. (The American Heritage® Stedman's Medical Dictionary 2002). It is a quantitative trait resulting from the interactions of multiple genetic and environmental determinants and has a normal distribution within the population (Kuneš and Zicha 2009, Hall 2012). Apart from this, BP is an important risk factor of cardiovascular (CVD) and renal diseases, significantly increasing cardiac risk with increased BP levels (Fredman et al. 1999, Danaei et al. 2011, WHO 2013).

There are several lines of evidence indicating that somatic growth and increase in levels of systolic (SBP) and diastolic (DBP) blood pressure are temporally synchronized although underlying pathways of these relationships are poorly understood (Cook et al. 1997, Leccia et al. 1998, Munter et al. 2004, Eriksson et al. 2007). Furthermore, BP and somatic growth increase at an accelerated rate during puberty when growth spurt occurs, secondary sexual characteristics appear and sexual dimorphism in somatic and physiological characteristics emerge (Tu et al. 2009).

Most studies have documented significant association between BP levels and anthropometric variables including body height and weight, body mass index (BMI), adiposity, obesity and abdominal obesity (He at al. 2000, Al-Sendi et al. 2003, Katzmarzick et al. 2004, Barba et al. 2006, Sorof et al. 2006, Beck et al. 2011).

Anthropometric abnormal weight indicators such as BMI (a measure of relative weight) can be determined easily and at low cost, accordingly may be a useful screening tool for predicting incident hypertension as early as in childhood (Beck et al. 2011, Moselakgomo et al. 2012). This however, requires adequate tools – reference values of a normal BP range. In order to meet this need, the main objective of this study was to provide sex- and BMI-specific percentile reference values for systolic and diastolic BP based on the adolescent Polish population, participants in the ADOPOLNOR study.

Materials and methods

A cross-sectional survey was carried out between February 2009 and September 2010 on a representative, randomly selected sample of adolescents, aged 10–18 years, participants in the ADOPOLNOR study, a transdisciplinary study on adolescent health and the quality of life. It was an ethnically homogeneous group of students in grades 5 through 6 of primary school, 1 through 3 of junior secondary and 1 to 2 of senior secondary schools in the Wielkopolska province and its capital, the city of Poznań. A more detailed description of the sampling procedure and the ADOPOLNOR study can be found elsewhere (Kaczmarek 2011).

The study design and study protocol were approved by the Bioethics Commission of the Poznań University of Medical Sciences (Resolution no. 311/07) and the Poznań Board of Education (Resolution WAF-405/1/JM/07). The survey was carried out in compliance with principles outlined in the Helsinki Declaration and subsequent amendments (WHO, 2001). Almost all parents (97.1%) provided written informed consent for their children to participate in the study. Additionally, 96.7% of young people aged between 16 and 18 gave us their written consent to be participants of the study.

All examinations were performed in school nursery rooms during morning hours. *Body height and weight were* measured by well-trained researchers according to standard procedures (Knussman 1988/1992). The BMI was calculated by taking a subject's weight (kg) and dividing it by his/her height squared (m^2). Chronological age was calculated in decimal values by subtracting the date of examination from the date of birth. The age groups were divided by years, defined in terms of the whole year; e.g. 10 years old group involved subjects between 10.00 and 10.99 years old. Blood pressure was measured by school nurses strictly following the guidelines of the Fourth Protocol of the American Working Group of High Blood Pressure in Children and Adolescents (2004). A fully calibrated TECH MED TM-Z mercury gauge sphygmomanometer with sets of exchangeable cuffs and a clinical stethoscope was used for BP measurements. The SBP and DBP were measured in duplicate on each of the three occasions separated by two day interval. Measurements were taken on the right arm with the subject sitting for at least 5 minutes rest and corresponded to the reading on the sphygmomanometer at the first and fifth phases of the Korotkow sounds, respectively. The average of the two measurements was the final result for the given day as it was suggested in the Seventh Report for adults (Chobanian et al. 2003). The scale on the sphygmomanometer was graduated in 2 millimetre Hg divisions. The readings were made to the nearest millimetre Hg. Calculated intra-observer error (intra-TEM) equalled 1.3 mmHg and inter-observer error (inter-TEM) equalled 2.3 mmHg (Krzyżaniak et al. 2009). The blood pressure classification was determined using the surveillance method. For each participant, the mean of measurements taken on each of the three occasions was calculated and served as his/her final BP value.

Data analysis Complete data on anthropometry and blood pressure measures were obtained for 2,451 male (mean age 14.44±2.58 years) and 2,490 female students (mean age 14.29±2.51 years) the total of 4,941. The dependent outcome variable was normal range of SBP and DBP variation, and the continuous independent (predictor) variable was age-adjusted BMI. Crude associations were evaluated using simple linear regression models which were fitted for SBP and DBP as dependent variables and BMI as predictors for each sex and age separately. Using the LMS method, fitted percentile curves were created for BMI-related SBP and DBP values (Cole and Green, 1992). Statistical analyses were performed using the STATISTICA 10.0 data analysis software system (StatSoft Inc. Tulsa, OK, USA). All significance tests comprised two-way determinations. A value of $p<0.05$ was considered statistically significant.

Results

Table 1 gives the mean and corresponding standard deviation for BMI, SBP and DBP by sex and age of the study sample.

The findings revealed that age related blood pressure pattern was similar in boys and girls. It showed a steady increase of SBP and DBP with age. The lowest and highest mean values were recorded in age category 10 and 18, respectively. There was a positive correlation between the SBP and DBP indicating that when SBP increased so did DBP (r=0.61 at $p<0.01$). Regarding sex differences, boys were likely to have relatively higher mean values of SBP and DBP than girls. Similar pattern was found for age-related changes in BMI.

Age-adjusted slopes of mean SBP and DBP on age-adjusted mean BMI are shown in Figure 1.

The relationship between the BMI and SBP and DBP was linear, positive and significantly different from zero at $p<0.001$, except for female DBP, significantly related to BMI at $p=0.048$. The slope for BMI-related

Table 1. Summary of body mass index, systolic and diastolic blood pressure of adolescent students by sex and age

Age (years)	Males				Females			
		BMI (kg/m²)	SBP (mmHg)	DBP (mmHg)		BMI (kg/m²)	SBP (mmHg)	DBP (mmHg)
	n	Mean±SD	Mean±SD	Mean±SD	n	Mean±SD	Mean±SD	Mean±SD
10	244	18.3±3.2	107.4±9.1	64.5±6.9	253	18.0±3.2	107.2±9.3	63.9±6.7
11	285	18.8±3.5	108.8±10.0	65.8±7.8	278	18.3±3.4	108.4±9.1	65.1±6.9
12	244	19.5±4.2	110.5±10.5	66.1±7.8	296	18.9±3.2	110.3±9.9	65.7±7.5
13	247	19.8±3.7	112.1±9.7	66.7±7.5	272	19.8±3.0	111.7±9.7	66.4±7.5
14	288	20.5±3.5	114.2±10.7	67.1±6.7	284	20.1±3.1	112.8±10.5	66.9±7.5
15	266	20.7±3.2	116.1±10.3	68.9±7.7	313	21.0±3.3	113.9±10.9	67.1±7.9
16	314	21.8±3.1	118.2±10.9	69.9±8.5	293	21.6±3.4	115.1±10.3	67.8±7.3
17	270	21.1±3.0	119.4±10.8	72.0±7.3	224	21.3±3.2	116.3±10.4	68.2±6.7
18	293	22.2±3.4	120.3±9.5	73.4±7.8	277	21.4±3.0	117.9±10.2	68.9±6.9

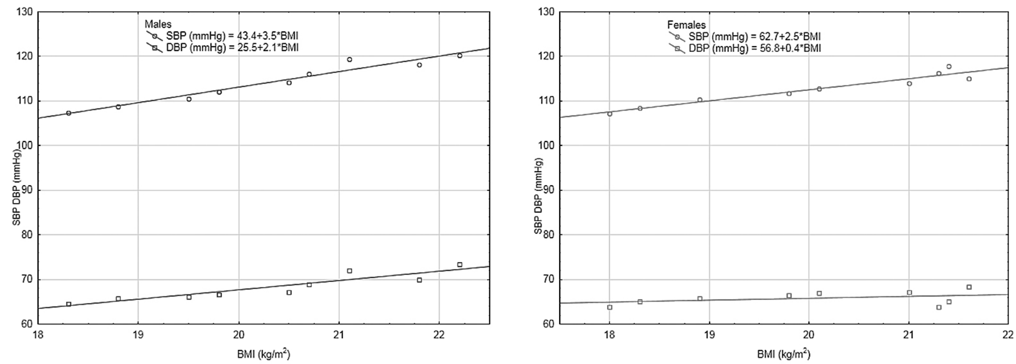

Fig. 1. Age-adjusted slopes of mean systolic and diastolic blood pressure on age-adjusted mean BMI in adolescent males (a) and females (b) aged 10–18 years

change in BP was much steeper for SBP than DBP in boys (β=0.91, 95% CI=0.56;1.27, adjusted R^2 =0.82) and girls (β=0.76; 95% CI=0.54–0.98; adjusted R^2 =0.61). The steeper rise in BMI-related SBP was higher in boys (β=0.97, 95% CI=0.77;1.18, adjusted R^2 =0.94) than in girls (β=0.96; 95% CI=0.72–1.2; adjusted R^2 =0.91). Conversely, slope of DBP on BMI was steeper in girls (β=0.95, 95% CI=0.69;1.22, adjusted R^2 =0.89 and β=0.92, 95% CI=0.56;1.27, adjusted R^2 =0.82 for girls and boys, respectively).

The LMS parameters and BMI-specific percentile values for SBP and DBP in ad-

Table 2. The LMS parameters and systolic blood pressure-for-BMI percentile values in adolescent males aged 10–18 years

BMI (kg/m²)	Males			Systolic blood pressure (mmHg) percentiles										
	L	M	S	3	5	10	15	25	50	75	85	90	95	97
12	–2.263	99.2	0.085	86.5	87.8	89.9	91.5	93.9	99.2	105.5	109.4	112.4	117.4	121.0
13	–1.817	101.0	0.085	87.8	89.2	91.4	93.1	95.6	101.0	107.3	111.2	114.0	118.7	122.0
14	–1.370	102.9	0.085	89.0	90.5	93.0	94.7	97.4	102.9	109.2	113.0	115.7	120.1	123.2
15	–0.931	104.8	0.085	90.4	92.0	94.5	96.4	99.2	104.8	111.2	114.9	117.5	121.7	124.5
16	–0.532	106.9	0.084	91.9	93.6	96.3	98.2	101.1	106.9	113.3	116.9	119.5	123.5	126.1
17	–0.211	109.1	0.084	93.5	95.3	98.1	100.1	103.2	109.1	115.5	119.1	121.6	125.5	128.0
18	–0.020	111.1	0.084	95.0	96.9	99.9	101.9	105.1	111.1	117.6	121.2	123.7	127.5	130.1
19	0.035	113.1	0.084	96.5	98.5	101.5	103.6	106.8	113.1	119.7	123.3	125.9	129.8	132.4
20	–0.068	114.9	0.085	98.1	100.1	103.2	105.3	108.6	114.9	121.7	125.5	128.1	132.2	134.9
21	–0.321	116.6	0.085	99.7	101.6	104.7	106.9	110.1	116.6	123.5	127.5	130.3	134.5	137.4
22	–0.654	117.9	0.086	101.2	103.1	106.1	108.2	111.4	117.9	125.1	129.2	132.1	136.7	139.8
23	–0.943	119.1	0.086	102.5	104.4	107.3	109.4	112.6	119.1	126.5	130.7	133.8	138.6	141.9
24	–1.219	120.4	0.086	103.9	105.7	108.6	110.6	113.8	120.4	127.8	132.2	135.4	140.5	144.0
25	–1.517	121.5	0.085	105.2	107.0	109.8	111.8	115.0	121.5	129.0	133.6	136.9	142.3	146.1
26	–1.858	122.5	0.085	106.5	108.2	110.9	112.9	116.0	122.5	130.2	134.9	138.4	144.1	148.1
27	–2.239	123.5	0.084	107.8	109.4	112.1	114.0	117.0	123.5	131.3	136.1	139.8	145.9	150.3
28	–2.614	124.4	0.084	109.0	110.6	113.2	115.0	118.0	124.4	132.3	137.3	141.1	147.6	152.4
29	–2.947	125.3	0.083	110.1	111.6	114.2	116.0	118.9	125.3	133.2	138.4	142.4	149.2	154.5
30	–3.213	126.1	0.083	111.1	112.6	115.1	116.9	119.8	126.1	134.1	139.4	143.5	150.8	156.4
31	–3.412	126.9	0.082	112.1	113.5	115.9	117.7	120.6	126.9	134.9	140.3	144.6	152.1	158.1
32	–3.579	127.7	0.082	112.9	114.4	116.8	118.5	121.4	127.7	135.7	141.2	145.6	153.4	159.6
33	–3.743	128.4	0.081	113.8	115.2	117.6	119.4	122.2	128.4	136.6	142.2	146.6	154.7	161.3
34	–3.910	129.3	0.081	114.7	116.1	118.5	120.2	123.0	129.3	137.5	143.2	147.7	156.1	163.0
35	–4.045	130.0	0.081	115.5	116.9	119.2	121.0	123.8	130.0	138.2	144.0	148.6	157.3	164.5

olescent males and females aged 10–18 years are shown in Tables 2 to 5. The quotation of 3rd, 5th, 10th, 15th, 25th, 50th, 75th, 85th, 90th, 95th, and 97th at any given BMI between 12 kg/m² and 35 kg/m² provided indication of the entire variation in BP of adolescent males and females aged 10–18 years. The BMI-specific charts for SBP and DBP, separately for boys and girls are shown in Figures 2 to 5.

Discussion

Current guidelines of the US Working Group on High Blood Pressure in Children and Adolescents (Fourth Report)

Table 3. The LMS parameters and diastolic blood pressure-for-BMI percentile values in adolescent males aged 10–18 years

BMI (kg/m²)	Males			Diastolic blood pressure (mmHg) percentiles										
	L	M	S	3	5	10	15	25	50	75	85	90	95	97
12	0.013	59.9	0.116	48.1	49.5	51.6	53.1	55.4	59.9	64.8	67.6	69.5	72.5	74.5
13	0.051	61.0	0.115	49.0	50.4	52.6	54.1	56.4	61.0	65.9	68.7	70.6	73.6	75.6
14	0.090	62.0	0.115	49.9	51.3	53.5	55.1	57.4	62.0	67.0	69.8	71.8	74.8	76.8
15	0.128	63.1	0.114	50.8	52.2	54.5	56.0	58.4	63.1	68.1	71.0	72.9	75.9	78.0
16	0.167	64.2	0.113	51.7	53.2	55.5	57.1	59.5	64.2	69.3	72.1	74.1	77.1	79.1
17	0.203	65.3	0.112	52.6	54.1	56.4	58.0	60.5	65.3	70.4	73.2	75.2	78.2	80.2
18	0.233	66.3	0.111	53.5	55.0	57.3	58.9	61.4	66.3	71.4	74.2	76.2	79.2	81.3
19	0.258	67.2	0.110	54.3	55.8	58.2	59.8	62.3	67.2	72.3	75.2	77.2	80.2	82.2
20	0.272	68.1	0.109	55.1	56.6	59.0	60.7	63.2	68.1	73.2	76.1	78.1	81.1	83.1
21	0.275	68.9	0.109	55.8	57.4	59.8	61.5	64.0	68.9	74.1	77.0	79.0	82.1	84.1
22	0.276	69.7	0.108	56.5	58.1	60.5	62.2	64.7	69.7	74.9	77.8	79.8	82.9	84.9
23	0.290	70.3	0.107	57.1	58.7	61.1	62.8	65.3	70.3	75.5	78.5	80.5	83.5	85.6
24	0.326	70.9	0.107	57.6	59.2	61.7	63.4	65.9	70.9	76.2	79.1	81.1	84.1	86.2
25	0.384	71.6	0.106	58.1	59.7	62.2	64.0	66.6	71.6	76.8	79.7	81.7	84.7	86.8
26	0.460	72.3	0.105	58.7	60.3	62.9	64.6	67.2	72.3	77.5	80.4	82.4	85.4	87.3
27	0.550	73.0	0.104	59.3	61.0	63.5	65.3	67.9	73.0	78.2	81.0	83.0	86.0	87.9
28	0.654	73.6	0.103	59.9	61.5	64.2	65.9	68.6	73.6	78.8	81.6	83.6	86.5	88.4
29	0.768	74.3	0.101	60.4	62.1	64.8	66.5	69.2	74.3	79.4	82.2	84.0	86.9	88.7
30	0.889	74.8	0.100	60.9	62.7	65.3	67.1	69.8	74.8	79.9	82.6	84.5	87.2	89.0
31	1.016	75.4	0.098	61.5	63.2	65.9	67.7	70.4	75.4	80.3	83.0	84.8	87.5	89.2
32	1.147	75.9	0.096	62.0	63.7	66.4	68.3	70.9	75.9	80.8	83.4	85.1	87.7	89.4
33	1.279	76.4	0.094	62.5	64.3	67.0	68.8	71.5	76.4	81.2	83.8	85.5	88.0	89.6
34	1.411	76.9	0.092	63.0	64.9	67.6	69.4	72.1	76.9	81.7	84.1	85.8	88.3	89.8
35	1.517	77.3	0.091	63.5	65.3	68.1	69.9	72.5	77.3	82.0	84.5	86.1	88.5	90.0

recommend arterial blood pressure to be evaluated against reference values presented in tables where BPs are categorised by body weight after adjusting for sex and age (2004). In our previous study, we provided national reference values for SBP and DBP for Polish children and adolescents aged 7–18 years after adjusting for sex, age and body height (Krzyżaniak et al. 2009). In this study, we present for the first time to our knowledge, age-adjusted, sex- and BMI-specific percentile reference values for SBP and DBP based on the adolescent Polish population aged

Table 4. The LMS parameters and systolic blood pressure-for-BMI percentile values in adolescent females aged 10–18 years

BMI (kg/m²)	Females			Systolic blood pressure (mmHg) percentiles										
	L	M	S	3	5	10	15	25	50	75	85	90	95	97
12	–1.587	100.9	0.075	88.9	90.2	92.3	93.8	96.1	100.9	106.3	109.6	111.9	115.7	118.3
13	–1.370	102.2	0.077	89.6	91.0	93.2	94.8	97.2	102.2	107.8	111.2	113.6	117.4	120.0
14	–1.152	103.6	0.078	90.4	91.8	94.2	95.8	98.4	103.6	109.4	112.8	115.2	119.1	121.7
15	–0.934	104.9	0.080	91.1	92.7	95.1	96.8	99.5	104.9	110.9	114.4	116.8	120.7	123.4
16	–0.720	106.2	0.081	91.9	93.5	96.0	97.9	100.6	106.2	112.3	115.9	118.4	122.3	124.9
17	–0.542	107.6	0.082	92.7	94.4	97.1	99.0	101.8	107.6	113.8	117.4	119.9	123.8	126.5
18	–0.435	108.9	0.083	93.6	95.4	98.2	100.1	103.1	108.9	115.3	119.0	121.5	125.5	128.1
19	–0.383	110.1	0.084	94.4	96.2	99.1	101.1	104.1	110.1	116.6	120.3	122.9	126.9	129.6
20	–0.373	111.0	0.085	95.1	96.9	99.8	101.8	104.9	111.0	117.6	121.3	124.0	128.1	130.8
21	–0.390	111.9	0.085	95.7	97.6	100.5	102.5	105.7	111.9	118.6	122.4	125.1	129.3	132.1
22	–0.406	112.9	0.086	96.5	98.3	101.3	103.4	106.6	112.9	119.8	123.7	126.5	130.7	133.6
23	–0.420	114.0	0.087	97.3	99.2	102.2	104.3	107.6	114.0	121.0	125.0	127.8	132.2	135.1
24	–0.443	115.2	0.088	98.2	100.1	103.2	105.3	108.6	115.2	122.4	126.5	129.3	133.8	136.8
25	–0.475	116.4	0.089	99.1	101.1	104.2	106.4	109.8	116.4	123.7	127.9	130.9	135.5	138.6
26	–0.499	117.7	0.089	100.1	102.1	105.3	107.5	110.9	117.7	125.1	129.4	132.4	137.1	140.3
27	–0.476	119.0	0.090	101.2	103.2	106.4	108.6	112.1	119.0	126.5	130.9	133.9	138.7	141.9
28	–0.385	120.3	0.090	102.2	104.2	107.5	109.8	113.3	120.3	127.9	132.3	135.3	140.1	143.2
29	–0.232	121.7	0.089	103.2	105.3	108.7	111.0	114.6	121.7	129.3	133.6	136.7	141.3	144.5
30	–0.023	123.2	0.089	104.3	106.5	109.9	112.4	116.0	123.2	130.8	135.1	138.0	142.6	145.6
31	0.233	124.7	0.088	105.3	107.6	111.3	113.7	117.5	124.7	132.3	136.5	139.5	143.9	146.8
32	0.528	126.3	0.087	106.4	108.8	112.6	115.1	119.0	126.3	133.9	138.0	140.8	145.1	147.9
33	0.853	127.9	0.087	107.3	109.9	113.8	116.5	120.5	127.9	135.4	139.5	142.2	146.3	149.0
34	1.198	129.5	0.086	108.2	110.9	115.1	117.9	122.0	129.5	137.0	140.9	143.6	147.6	150.1
35	1.552	131.1	0.085	109.0	111.9	116.3	119.2	123.5	131.1	138.5	142.4	145.0	148.9	151.3

10–18 years. Our findings demonstrated linearity in the relationship between BP (SBP and DBP) and BMI in both boys and girls. Furthermore, they also showed a consistently steeper slope of SBP than DBP in the study sample. Adolescent males were likely to have relatively higher mean values of SBP, DBP and BMI than females. These findings are in line with the adolescent-emergent model (AEM) which states that adolescence and, especially, the age of pubescence seems to be critical for the appearance of sexual dimorphism in BP which commonly per-

Table 5. The LMS parameters and diastolic blood pressure-for-BMI percentile values in adolescent females aged 10–18 years

BMI (kg/m^2)	Females			Diastolic blood pressure (mmHg) percentiles										
	L	M	S	3	5	10	15	25	50	75	85	90	95	97
12	–0.019	60.3	0.110	49.1	50.4	52.4	53.8	56.0	60.3	64.9	67.6	69.4	72.2	74.1
13	–0.023	61.1	0.109	49.8	51.1	53.2	54.6	56.8	61.1	65.8	68.4	70.3	73.1	75.0
14	–0.027	61.9	0.108	50.6	51.9	54.0	55.4	57.6	61.9	66.6	69.3	71.1	74.0	75.9
15	–0.036	62.8	0.107	51.4	52.7	54.8	56.2	58.4	62.8	67.5	70.2	72.0	74.9	76.8
16	–0.034	63.7	0.106	52.3	53.6	55.7	57.1	59.3	63.7	68.4	71.1	73.0	75.9	77.8
17	0.000	64.7	0.105	53.1	54.4	56.5	58.0	60.2	64.7	69.4	72.1	74.0	76.8	78.7
18	0.059	65.5	0.104	53.8	55.2	57.3	58.8	61.1	65.5	70.3	73.0	74.9	77.7	79.6
19	0.129	66.3	0.104	54.4	55.8	58.0	59.5	61.8	66.3	71.1	73.8	75.7	78.5	80.4
20	0.181	66.9	0.104	54.9	56.3	58.5	60.0	62.4	66.9	71.8	74.5	76.3	79.2	81.1
21	0.213	67.5	0.104	55.2	56.7	58.9	60.5	62.9	67.5	72.4	75.1	77.0	79.9	81.8
22	0.244	68.0	0.105	55.5	57.0	59.3	60.9	63.3	68.0	73.0	75.8	77.7	80.6	82.5
23	0.278	68.6	0.106	55.8	57.3	59.7	61.3	63.8	68.6	73.7	76.5	78.4	81.4	83.4
24	0.301	69.2	0.108	56.1	57.7	60.1	61.8	64.3	69.2	74.4	77.3	79.3	82.3	84.3
25	0.296	69.8	0.110	56.4	58.0	60.4	62.1	64.7	69.8	75.1	78.0	80.1	83.2	85.2
26	0.253	70.3	0.111	56.7	58.3	60.8	62.5	65.1	70.3	75.7	78.7	80.8	84.0	86.2
27	0.194	70.8	0.113	57.0	58.6	61.1	62.9	65.6	70.8	76.3	79.4	81.6	84.9	87.1
28	0.143	71.2	0.114	57.4	59.0	61.5	63.3	66.0	71.2	76.9	80.1	82.3	85.7	87.9
29	0.103	71.7	0.114	57.7	59.3	61.9	63.7	66.4	71.7	77.5	80.7	83.0	86.4	88.7
30	0.075	72.2	0.115	58.1	59.7	62.3	64.1	66.8	72.2	78.0	81.3	83.6	87.2	89.5
31	0.053	72.8	0.116	58.5	60.1	62.7	64.5	67.3	72.8	78.7	82.0	84.4	87.9	90.3
32	0.039	73.4	0.116	58.9	60.6	63.2	65.0	67.8	73.4	79.3	82.7	85.1	88.7	91.2
33	0.035	74.0	0.117	59.3	61.0	63.7	65.5	68.4	74.0	80.0	83.4	85.8	89.5	92.0
34	0.036	74.5	0.117	59.7	61.4	64.1	66.0	68.9	74.5	80.7	84.1	86.6	90.3	92.8
35	0.041	75.1	0.118	60.2	61.9	64.6	66.5	69.4	75.1	81.3	84.9	87.3	91.1	93.7

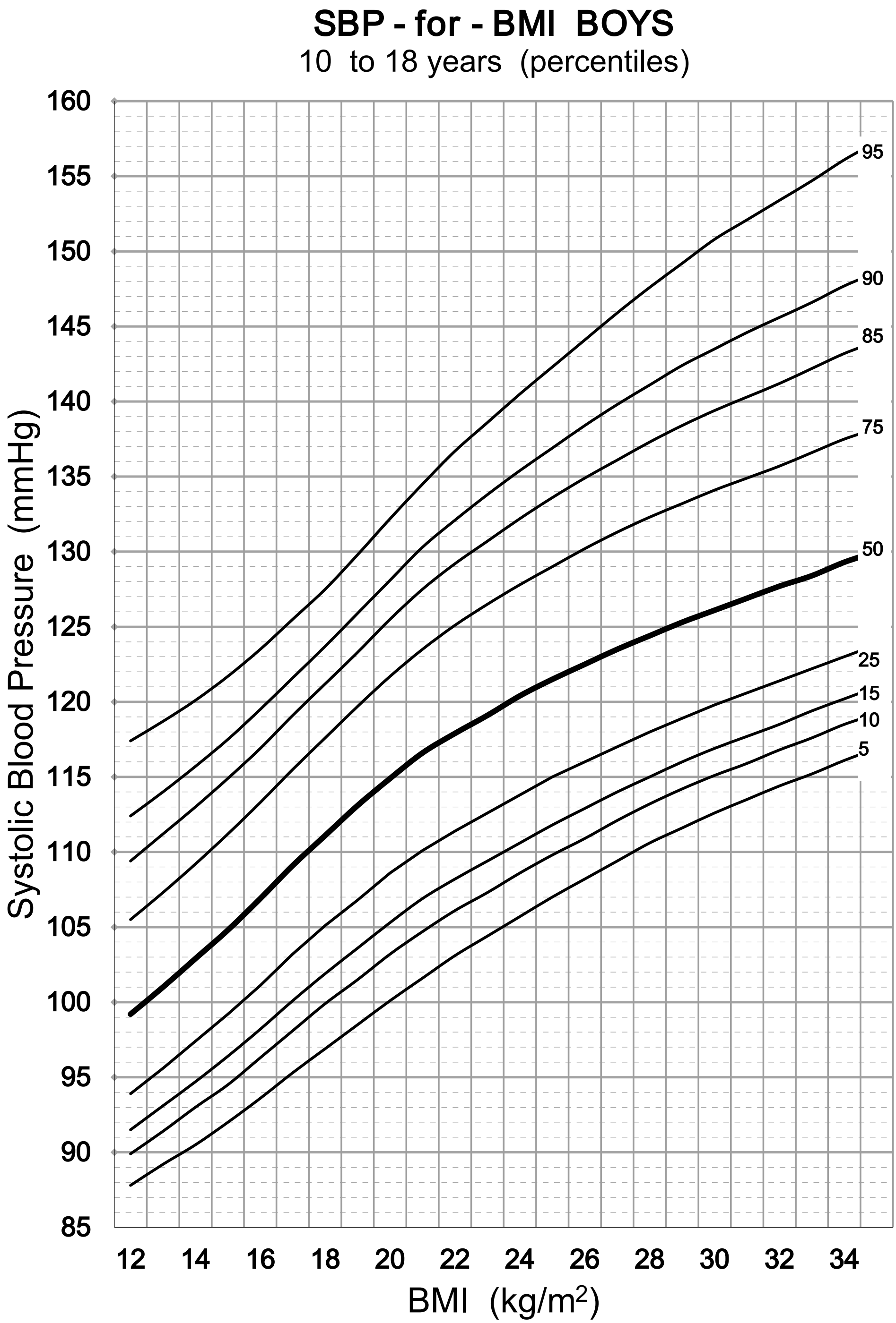

Fig. 2. The BMI-specific percentile charts for systolic blood pressure in adolescent males aged 10–18 years

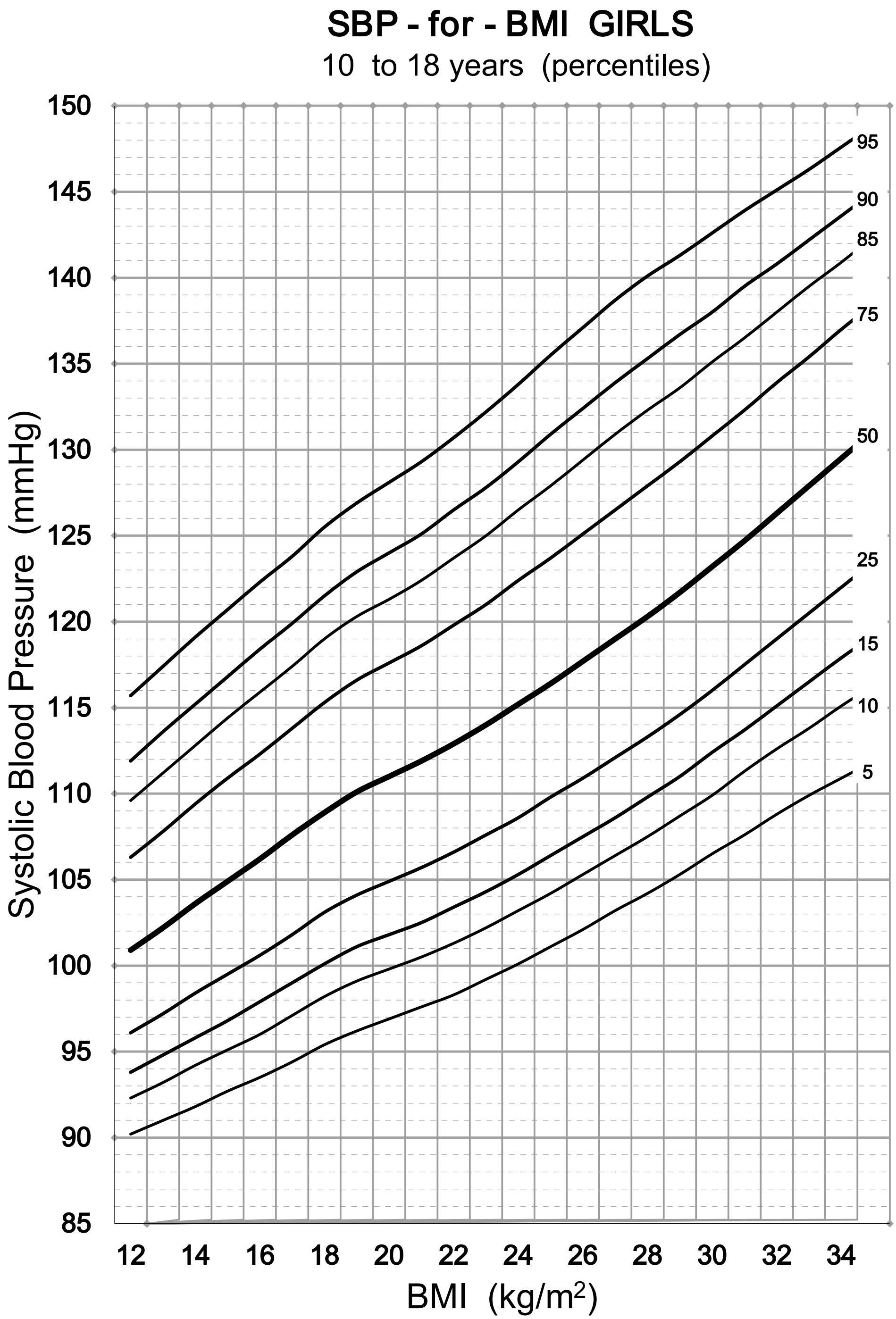

Fig. 3. The BMI-specific percentile charts for systolic blood pressure in adolescent females aged 10–18 years

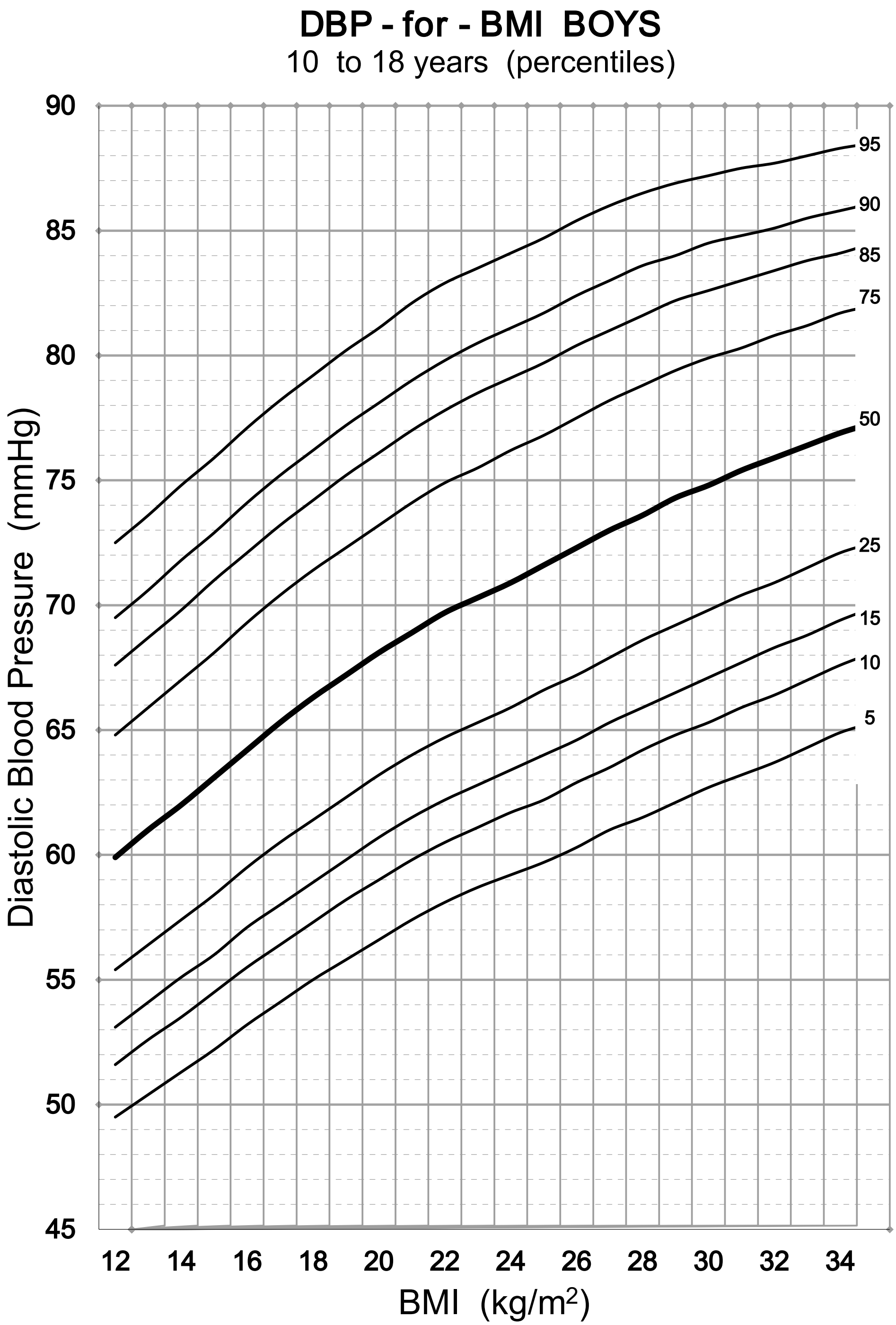

Fig. 4. The BMI-specific percentile charts for diastolic blood pressure in adolescent males aged 10–18 years

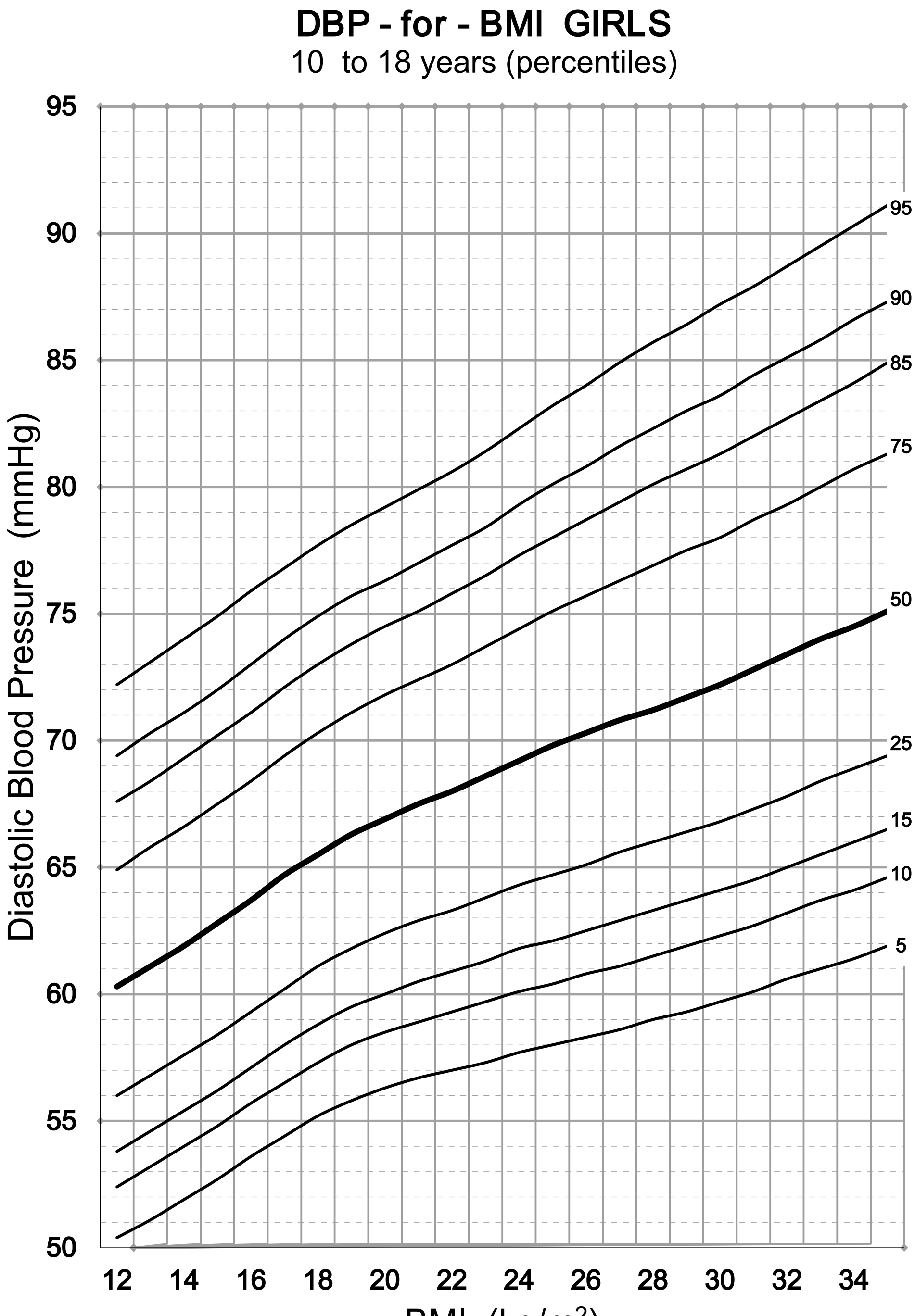

Fig. 5. The BMI-specific percentile charts for diastolic blood pressure in adolescent females aged 10–18 years

sists throughout adulthood (Shankar et al. 2005, Dasgupta et al. 2006, Tu et al. 2009). This is most likely due to the activation of gonadal hormones with possibly a preponderant effect of testosterone involved during sexual maturation as well as acceleration in somatic growth during pubertal growth spurt (Bogin 2005). While the rise in the BP level during puberty may be of a temporary nature, there may be an increased future risk of elevated blood pressure due to multiple risk-for-health behaviours taken by adolescents (Chen 2008).

Data from epidemiological studies provide evidence for the rising trend toward elevated blood pressure in children and adolescents (Krzyżaniak et al. 2003, Ostrowska-Nawarycz and Nawarycz 2007, Kułaga et al. 2009). Our recent study has demonstrated that the overall prevalence of elevated BP was 6.6% for prehypertension and 8.9% for hypertension for SBP and/or DBP combined (Kaczmarek et al. 2015). These data indicate that the prevalence of systemic hypertension in the juvenile population in Poland has doubled over the last decade. Krzyżaniak and colleagues, in the national study of BP conducted in 2000 among Polish school children (7–19 years) reported the prevalence rate of hypertension ~4% (Krzyżaniak et al. 2003). Similar figures, 4.9% for hypertension and 11.1% for prehypertension (high normal BP) were found in a large sample study of children and adolescents, aged 7 to 19 years in the city of Lodz, Poland (Ostrowska-Nawarycz and Nawarycz 2007). It is suggested that this upward slope of high blood pressure prevalence in the under-18 population may be attributed at least in part to the rapid increase in overweight and obesity (Jodkowska et al. 2010, Grajda et al. 2011) and the high prevalence of sedentary behaviours, physical inactivity and unhealthy dietary habits (Durda 2011, Kaczmarek 2012). According to recent data from the national survey in Poland, the prevalence of overweight and obesity in 6–19-year-old children and adolescents is 16.4% (18.7% and 14.3%, boys and girls respectively), and underweight – 12.0% total (10.0% – boys, 13.7% – girls) (Grajda et al. 2010). Abnormal weight status and unhealthy dietary habits are two additive factors which affect elevated blood pressure in adolescence and due to phenomenon of tracking elevated blood pressure from adolescence to adulthood may significantly increase risk for cardiovascular disease in later life (Berenson et al. 1999.

Conclusion

The physical growth of children and adolescents has been recognized as an important indicator of health and well-being. Growth charts for somatic traits are commonly used in auxological and pediatric examination in order to assess an individual's growth status against his/her peers. In the context of recent upward trends toward elevated blood pressure and increased BMI, the sex- and BMI-specific reference values/charts of SBP and DBP may be a useful tool in monitoring BP for early detection of its elevated level and treatment of children and adolescents with high blood pressure.

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Authors' Contributions

AK coordinated medical research, conceived the paper and drafted the manuscript; MK was the ADPOLNOR project manager, conceived study design, coordinated the research and drafted the manuscript; BS-W, MK-W and AS made contributions to the design of medical research, analysed and interpreted the data, and revised the content of the manuscript. All authors critically read and approved the final manuscript.

Conflict of interest

The authors declare that there is no conflict of interests regarding the submitted paper.

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