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ORIGINAL ARTICLE

Preschool children blood pressure percentiles by age and height

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We aimed to construct blood pressure (BP) references for the Polish preschool children and to compare them with the United States, German and European references. BP was measured oscillometrically using a validated device in 4378 randomly selected Polish children aged 3–6 years who were free of chronic diseases and behaved quietly during BP measurement. Height and weight were also measured. Gender-specific BP percentiles were constructed for age and height simultaneously with the use of quantile regression and a polynomial regression model. Systolic blood pressure (SBP), diastolic blood pressure (DBP) and mean arterial blood pressure reference percentiles by gender, age and height are presented. The Polish preschool children's 90th and 95th SBP and DBP percentiles were mostly lower than those in the United States, German and IDEFICS study BP references. Compared with the German oscillometric BP reference and with the United States sphygmomanometric BP reference, differences in the 95th SBP percentiles ranged by age from − 5 to 0 mm Hg and from − 2 to − 1 mm Hg, in boys and girls, respectively, whereas the differences in the 95th percentiles of DBP ranged from − 7 to − 1 mm Hg and from − 5 to − 1 mm Hg, in boys and girls, respectively. Polish preschool children's BP percentiles based on measurements with the use of a validated oscillometric device in a nationally representative sample are lower than those from the current United States, German and European references. When interpreting BP measurements in children, adequate referential values should be used.

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INTRODUCTION

Current guidelines recommend routine measurement of blood pressure (BP) in children over 3 years of age.[1,2] This recommendation is based on the findings that BP measured early in life predicts BP in adolescence and adulthood[3,4] and that hypertension in youth may lead to target organ damage.[5] In children and adolescents, owing to lack of clinically defined, health-risk-related cut-off levels for increased BP, age- and sex-specific population-based distributions of BP (90th and 95th percentiles) are used to define normal BP thresholds. Currently, much clinical practice uses automated oscillometric devices for BP measurements. In Poland, BP references for oscillometric and sphygmomanometric methods are available for school-aged children and adolescents,[6,7] but there are no BP references for preschoolers.

The aim of our study was to develop age- and gender-specific reference ranges for BP measured with a validated, automated oscillometric device in Polish preschool children and to study BP associations with basic anthropometric traits. We also compared BP percentiles with the United States, German and recently published IDEFCS study references. Further, we compared BP percentiles of total sample reference with reference constructed using data from non-overweight children.

MATERIALS AND METHODS

We analysed the blood pressure and anthropometric data collected in the course of population-based cross-sectional OLA study (blood pressure references for Polish preschool children-N R13 0002 06). Field examinations were conducted in 81 primary health care practices in all regions of Poland between November 2010 and May 2012. Approval of the Children's Memorial Health Institute Ethics Committee to conduct the study was obtained before the study commenced.

Subjects

Study participants (children 3–6 years of age) were randomly selected using two-stage sampling. The sampling frame at the first stage consisted of a list of primary health care practices obtained from regional offices of the National Health Fund. Sampling was stratified by province. In the second stage, all children in the required age range within the sampled primary health care setting were included in the sampling frame. This sampling method ensured national representativeness of Polish children aged 3–6 years because all children in Poland are covered by national health insurance scheme and registered at primary health care practices. The sample size was determined based on work of Guo *et al*.[8] To enable precision of the percentile estimates, approximately 500 children in sex- and age-specific group was required. Based on previous experience of 70% response rate,[7] 7500 preschool children were planned to be sampled. Informed consent was obtained in a written form from a parent or legal guardian of each participating child. The medical history of study participants, including birth weight, past and present medical conditions and medications used within the last 30 days before study enrolment, was obtained from the parent/guardian assisting child. A physician, mostly paediatrician, examined each participating child. The examination was conducted according to standard protocol established in line with Polish Ministry of Health decree for children's health check-up. A child was considered healthy when he or she was free from congenital, chronic or acute disorders and medications possibly affecting growth or BP levels. Anthropometric and blood pressure measurements were conducted by trained personnel according to standard procedure defined by study protocol.

Anthropometric techniques

Height was measured in duplicate using a SECA 214 stadiometer (Seca GmbH & Co KG, Hamburg, Germany). Each subject was in a standing upright position with shoes off, with hips and shoulders perpendicular to the central axis, heels against the footboard, knees together, arms hanging loosely at the sides and the head in the Frankfurt plane. Height was

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recorded to the nearest millimetre. If a difference between the two measurements exceeded 4 mm, a third measurement was performed. With subjects wearing light underwear, the body weight was recorded to the nearest 0.05 kg, using a digital medical scale (Radwag WPT 100/200, Radom, Poland). In the case of a difference between measurements of 0.3 kg or more, a third measurement was taken.

BP measurement

BP was recorded at least 30 min after a meal, using a Datascope Accutorr Plus (Datascope Corp, Fairfield, NJ, USA), an automated oscillometric device that has been validated for use in children.[9] Temperature at the primary care clinics was kept between 20 and 26 °C at the time of BP measurements. The appropriate cuff size (bladder width at least 40% of arm circumference and length 80–100% of arm circumference) was determined by measuring the mid-upper arm circumference. The cuff was applied to the right arm and then wrapped to a tightness that allowed two fingers to be inserted under the cuff. BP was measured in triplicate at 1- to 2-min intervals after 5–10 min of rest in a sitting position with the arm and back supported, cuff at the level of the heart. Initial pressure of cuff inflation was set to 140 mm Hg. For the second and third measurement, Datascope Accutorr Plus device automatically adjusted cuff inflation pressure to the previous systolic BP (SBP) reading. The mean of the second and third measurements was used for analysis. The child was allowed to sit on the parent's lap when it was necessary to improve compliance with BP measurement. All the measurements were taken by trained staff (physicians, nurses, anthropologists, public health professionals) using standard and calibrated equipment. The child's behaviour during BP measurement was assessed by the investigator according to the following criteria: (i) quiet, (ii) moving actively, (iii) crying.

Statistical analysis

Statistical analyses were performed separately for boys and girls using SAS 9.3 software (SAS Institute, Inc, Cary, NC, USA). Trends for children who did not agree to BP measurement and children who moved or cried during the BP measurement procedure across age categories were tested using Cochran–Armitage trend test. Height *z*-scores were calculated relative to the Polish 2012 growth references.[10] Overweight and obesity status according to the International Obesity Task Force definition[11] was determined using the LMSGrowth software.[12] Differences in the prevalence of overweight including obesity between sex groups were tested using a chi-squared test. The sex differences in means of normally distributed variables: height, birth weight and BP were tested with the use two-samples *t*-test, whereas in the comparison of variables not meeting assumptions of the parametric tests: age, weight, BMI, Mann–Whitney test was applied. The averages of the first, second and third BP measurements were compared with the use of paired *t*-test. The *P*-values less than 0.05 were considered significant. For the SBP, mean arterial BP (MAP) and diastolic BP (DBP) percentile construction, we applied two different analytical methods: polynomial regression and quantile regression (QR). We used exact ages in the models. For the purpose of grouping, the age values were rounded to the nearest integer.

Polynomial regression. Polynomial regression is a parametric technique, therefore models were fitted on log-transformed BP data, which eliminate the heteroscedasticity.[13,14] SBP, MAP and DBP were separately regressed stepwise with age (with up to a polynomial of terms: age, age^2, age^3 and age^4) and height *z*-score (with up to a polynomial of terms: z, z^2, z^3 and z^4) according to the following equation:

$$\ln BP = \alpha + \beta_1 z + \beta_2 z^2 + \beta_3 z^3 + \beta_4 z^4 + \beta_5(\text{age}-4.5) + \beta_6(\text{age}-4.5)^2 + \beta_7(\text{age}-4.5)^3 + \beta_8(\text{age}-4.5)^4 + s \times z_\alpha$$

where s denotes the standard deviation of residual, and $z_\alpha = -2.32635$, $z_\alpha = -1.64485$, $z_\alpha = -1.28155$, $z_\alpha = 0$, $z_\alpha = 1.28155$, $z_\alpha = 1.64485$, $z_\alpha = 2.32635$ for the 1st, 5th, 10th, 50th, 90th, 95th and 99th percentiles, respectively.

The regression equations were then used to estimate the expected SBP, MAP and DBP at specific age and height 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles. Obtained polynomial coefficients were applied to compute the specific age and height BP percentiles. lnBP was then transformed back to BP.

Quantile regression. QR proposed by Koenker and Bassett,[15] provides an alternative approach to fitting BP percentiles. QR is nonparametric and, compared with the ordinary linear regression, is free of distributional assumptions, and is not influenced by outliers of the dependent variable. QR models provide a better fit to the data.[16,17] Using PROC QUANTREG in SAS, we fitted conditional BP quantiles: 0.01, 0.05, 0.1, 0.5, 0.9, 0.95 and 0.99 for age and height.

Assessing goodness of fit

To assess the goodness-of-fit distribution of observed and expected frequencies of BP in percentile bands <1, 1–4.9, 5–9.9, 10–49.9, 50–89.9, 90–94.9, 95–98.9 and $\geqslant 99$ were compared using a chi-square goodness-of-fit test.

Comparison with chosen BP references

The OLA study 90th and 95th SBP and DBP reference percentiles at median height were compared with the corresponding percentiles of the United States BP reference,[1] oscillometric BP references from Germany (the KiGGS study)[18] and the IDEFICS study BP references.[19] In children, SBP or DBP readings that are greater than or equal to the 90th percentile, but less than the 95th percentile and SBP and/or DBP that is greater than or equal to the 95th percentile is defined as prehypertension and hypertension, respectively.[1] The United States BP reference was chosen for comparison because it is actually used by primary health care physicians in Poland. In turn, German and the IDEFICS study BP references were chosen because they were developed with the use of oscillometric devices based on the European data. In the case of the 95th percentile, the comparison was limited to German and United States BP references, because IDEFICS study BP references did not provide values for this percentile. In all the compared references, BP percentiles were modelled by age and height simultaneously. Median height was similar in the case of the OLA, KiGGs and IDEFICS studies. In the case of the United States references, height was adjusted to European values—we used BP at the 75th height percentile of the United States BP reference. In comparison, the OLA study BP percentiles were predicted for ages: 3.5, 4.5, 5.5 and 6.5. SBP, DBP and MAP reference percentiles were fitted for non-overweight children in the sample with the use of regression models. The differences in frequencies of SBP, MAP and DBP $\geqslant$95th percentile between total sample reference and non-overweight reference were compared using chi-square test.

Table 1. Children who did not agree to BP measurement or who moved or cried during taking BP measurement

Age (years)	Boys			Girls		
	N	*Did not agree to BP measurement* N *(%)*	*Moving and/or crying* N *(%)*	N	*Did not agree to BP measurement* N *(%)*	*Moving and/or crying* N *(%)*
3	627	32 (5.1)	110 (17.5)	610	24 (3.9)	97 (15.9)
4	680	15 (2.2)	58 (8.5)	705	17 (2.4)	62 (8.8)
5	622	5 (0.8)	32 (5.1)	663	11 (1.7)	29 (4.4)
6	566	4 (0.7)	16 (2.8)	577	4 (0.7)	12 (2.1)
	P[a]	< 0.0001	< 0.0001		< 0.0001	< 0.0001
3 – 6	2495	56 (2.2)	216 (8.7)	2555	56 (2.2)	200 (7.8)

Abbreviation: BP, blood pressure. [a]Cochran–Armitage trend test for change with age.

RESULTS

Out of 7545 children sampled and invited to take part in the study, parents of 5050 children aged 3–6 years reported to the primary care clinics with their child, consented and were enrolled in the study (response rate of 0.67). One hundred and twelve children did not agree to a blood pressure measurement (Table 1). Data from 55 children were excluded due to medical reasons (that is. treatment with systemic steroids, diabetes, cancer, congenital heart defect, coarctation of the aorta, muscular dystrophy or acute upper respiratory tract infection on day of examination). Data on height and/or on BP was missing or invalid in the case of 89 children. We excluded data from 416 children who were moving and/or crying during BP measurement (Table 1), leaving 2229 girls and 2149 boys for analysis. The characteristics of population under investigation are presented in Table 2. Boys were taller (1.4 cm), heavier (0.6 kg) and had higher birth weight (160 g) compared with girls ($P<0.001$), whereas SBP, MAP and DBP were higher in girls than in boys: 0.7, 0.7, 0.9 mm Hg ($P<0.01$), respectively. The first SBP, MAP and DBP measurement yielded the highest values in the series of three readings, whereas the third measurement yielded the lowest values. The differences between the first and second readings were in range from 1 mm Hg to 1.7 mm Hg, whereas the differences between the second and third readings were in range 0.7–1.1 mm Hg; the differences were highly statistically significant ($P<0.001$).

Results of the polynomial regression models are presented in Table 3. Obtained polynomial coefficients enable to calculate BP *z*-score for age and height simultaneously.

Resultant age- and height-specific SBP, MAP and DBP percentiles for boys and girls from QR models are presented in Table 4. In general, SBP, MAP and DBP percentiles increase with age and height with the exception of the 99th DBP percentile which, in the case of boys, decrease with age, whereas, in the case of girls decrease with height across each age category. Mean difference between QR models and polynomial regression models in obtained SBP percentiles <99th was, in the case of boys and girls, 0.2 mm Hg, whereas at the 99th percentile it was 0.8 and 1.3 mm Hg for boys and girls, respectively. Mean difference between QR models and polynomial regression models in obtained MAP percentiles <99th was 0.1 mm Hg and 0.0 mm Hg for boys and girls, respectively, whereas at the 99th percentile it was 1.4 and 0.3 mm Hg for boys and girls, respectively. In the case of DBP, mean difference between percentiles <99th was −0.2 mm Hg and −0.4 mm Hg for boys and girls, respectively, whereas at the 99th was 0.3 mm Hg and −0.5 mm Hg for boys and girls, respectively.

QR model compared with the polynomial regression provided better fit of constructed SBP, MAP and DBP percentiles to the data. The goodness-of-fit of quantile regression model is excellent, with no significant differences between observed and expected counts (Table 5). Differences between the observed and the expected counts in the case of QR model were lower in comparison with polynomial regression model (data not shown).

In the case of Polish boys aged 3–4 years, the 90th percentile of SBP was 3–5 mm Hg lower than the corresponding SBP percentiles of United States reference, IDEFICS study reference and German reference. The differences were smaller in boys aged 5–6 years: 4 mm Hg in the case of the United States reference and the IDEFICS study reference and 1 mm Hg in comparison with German reference. The 90th DBP percentile in 3-year-old Polish boys was 1 mm Hg higher than the United States BP reference, and 4–6 mm Hg lower than the German and the IDEFICS study references. In boys aged 4–6 years, the 90th DBP percentile of the OLA study was 3–6 mm Hg lower than other references (Figure 1a).

In the case of 3-year-old girls, the 90th SBP and DBP percentile of the OLA study were equal to the corresponding percentiles of the United States BP reference, but 2–6 mm Hg lower than other references. In 4–6-year-old Polish girls, the 90th percentile of SBP and DBP were 1–6 mm Hg lower than other references. The difference was smallest when comparing the 90th percentile of SBP between the OLA study and the United States BP references: 1–2 mm Hg (Figure 1b).

At the corresponding height, differences in the 95th SBP percentiles in the case of boys ranged from −5 mm Hg to −4 mm Hg and from −4 mm Hg to 0 mm Hg, for the United States and German references, respectively; in the case of girls, from −2 mm Hg to −1 mm Hg in both the United States and German reference. Differences in the 95th DBP percentile in the case of boys ranged from −7 mm Hg to −1 mm Hg and from −5 mm Hg to −3 mm Hg in the United States and German reference, respectively; and in the case of girls from −5 mm Hg to −1 mm Hg and from −4 mm Hg to −3 mm Hg in the United States and German reference, respectively (Figure 2). Blood pressure percentiles fitted with the use of data from non-overweight children in the OLA study were slightly lower compared with BP percentiles fitted with the use of data from the total sample. At median height differences in the 50th percentiles of SBP, DBP and MAP between OLA reference sample and OLA non-overweight sample were equal to or less than 1 mm Hg for both boys and girls. In general, in the 95th SBP, DBP and MAP percentiles differences were close to 1 mm Hg and did not exceed 2 mm Hg (Figure 3). However, frequencies of BP readings equal or higher than 95th percentile of the non-overweight reference compared with the total sample reference were higher: 1.6, 1.4 and 0.7% for SBP, MAP, DBP, respectively ($P<0.05$).

Table 2. Baseline characteristics of the reference population aged 3–6 years

	Boys		*Girls*		*Sex difference P-value*
	N	*Mean (s.d.)/% (s.e.)*	N	*Mean (s.d.)/% (s.e.)*	
Age (years)	2149	4.6 (1.08)	2229	4.6 (1.08)	0.643
Birth weight (g)	2128	3474.9 (553.64)	2213	3313.6 (536.11)	<0.001
Height (cm)	2149	108.8 (8.69)	2229	107.4 (8.64)	<0.001
Weight (kg)	2148	18.9 (4.09)	2227	18.3 (4.01)	<0.001
BMI (kg m^{-2})	2148	15.8 (1.79)	2227	15.7 (1.77)	0.091
Overweight (%) (including obesity)	2148	11.7 (0.74)	2227	14.7 (0.81)	0.004
SBP (mm Hg)	2149	94.4 (7.65)	2229	95.1 (7.85)	0.005
MAP (mm Hg)	2125	70.5 (6.04)	2210	71.2 (6.30)	<0.001
DBP (mm Hg)	2149	55.3 (6.43)	2229	56.2 (6.80)	<0.001

Data are shown as means (s.d.) and % (s.e.).

Table 3. Regression coefficients obtained from polynomial regression models for lnBP

	lnSBP				*lnMAP*				*lnDBP*			
	Boys		*Girls*		*Boys*		*Girls*		*Boys*		*Girls*	
	β	P-*value*	β	P-*value*	β	P-*value*	β	P-*value*	β	P-*value*	β	P-*value*
Intercept	4.5386	< 0.0001	4.5452	< 0.0001	4.2496	< 0.0001	4.2587	< 0.0001	4.0076	< 0.0001	4.0215	< 0.0001
Age												
Age − 4.5	0.0055	0.1474	0.0183	< 0.0001	0.0067	0.0995	0.0155	0.0002	0.0031	0.5785	0.0192	0.001
$(\text{Age} - 4.5)^2$	0.0004	0.9368	0.0027	0.6134	− 0.0049	0.3785	0.0033	0.5635	− 0.0107	0.1646	− 0.0014	0.8656
$(\text{Age} - 4.5)^3$	0.0025	0.1363	− 0.0035	0.0329	0.0021	0.2364	− 0.0019	0.3005	0.0037	0.1374	− 0.0030	0.2363
$(\text{Age} - 4.5)^4$	0.0004	0.796	0.0004	0.7844	0.0015	0.396	− 0.0004	0.8365	0.0030	0.2027	0.0008	0.7378
Height z-score												
Zht	0.0105	< 0.0001	0.0106	< 0.0001	0.0098	0.0004	0.0102	0.0001	0.0111	0.0039	0.0083	0.0265
Zht^2	0.0034	0.0644	0.0022	0.259	0.0030	0.1291	− 0.0005	0.8129	0.0016	0.565	− 0.0014	0.6181
Zht^3	0.0008	0.2103	0.0005	0.3754	0.0007	0.3006	0.0003	0.6162	0.0004	0.6816	0.0007	0.405
Zht^4	− 0.0004	0.1043	− 0.0003	0.2399	− 0.0003	0.2092	0.0000	0.8446	− 0.0001	0.811	0.0000	0.9842
Residual s.d.	0.0776		0.0795		0.0826		0.0860		0.1148		0.1204	

Abbreviations: BP, blood pressure; DBP, diastolic BP; MAP, mean arterial BP; SBP, systolic BP.

DISCUSSION

The study presents SBP, MAP and DBP references by age and height simultaneously for girls and boys aged 3–6 years. BP percentiles were constructed using data from a large, nationally representative population sample of preschool children in Poland. In the analysis, we included data obtained from healthy children who were quiet during BP measurements. Despite the presence of a reassuring parent and a possibility to take the BP measurement while on a parent's lap, some children did not cooperate with the investigator during BP measurement or displayed high level of distress. To our best knowledge, only two research teams had previously reported the behaviour of preschool children during BP measurements.[20,21] In our sample, over 10% of children did not agree to BP measurement or presented distress during the procedure, which was much higher compared to the frequency reported by Japanese researchers for the similar age range.[21] Not surprisingly, a child's attitude and behaviour during BP measurement was age dependent, with older children being more cooperative and quiet during the procedure. Australian researchers report over 42% of 1-year-old children being active or crying during BP measurement,[20] which is higher than the frequency among 3-year-old participants of the OLA study. In the recently published results of IDEFCIS study presenting BP references for children aged 2.0–10.9 years, data from almost 10% of participants 'from whom BP data were missing, who were on average slightly younger than those included' were excluded.[19] The IDEFICS study researchers did not mention the exclusions due to active or crying child's behaviour during BP measurement but it could not be precluded. Observation of young childrens' behaviour during BP measurement is important because readings may not be interpretable in every child in preschool age due to distressful behaviour.

BP percentiles were obtained using QR method for fitting paediatric growth data. In general, in comparison with polynomial regression, goodness of fit of the QR model was better, with no significant difference between observed and expected frequencies of BP in percentile bands, which is consistent with the results of other authors, who used QR for blood pressure reference construction.[16,22] QR is a flexible statistical technique that does not impose normality assumption on the data. This method allows the use of unusual observation and determination of percentiles in the case of skewed distribution of dependent variable, which is a typical situation for biological data.[23] Polynomial regression, which was used to construct BP percentiles in the United States,[1] Poland,[6,7] Norway,[13] enables BP conversion to BP *z*-scores. The advantages of using BP *z*-scores as standardised quantities are comparability across ages and sexes, and the ability to analyse data as a continuous variable.

Current European guidelines on management of high blood pressure in children recommend that 'if hypertension is detected by the oscillometric methods, it must be confirmed by the auscultatory method'.[2] Following this recommendation and in line with authors of IDEFICS study blood pressure references,[19] we consider blood pressure percentiles developed by the OLA study useful to identify increased blood pressure levels among preschool children during screening examination. Diagnosis of hypertension should be confirmed using auscultatory method for multiple testing taken at different time points.

Comparison of the 90th and 95th SBP and DBP reference percentiles for the corresponding height with the United States, German and IDEFICS study BP references, revealed that the OLA study reference percentiles were the lowest, however, lack of significance testing of differences is the limitation of the comparison. With regard to the fourth report, the difference in BP percentiles may partially be attributable to the use of oscillometric BP measurement in the OLA study, which provides BP readings that are 0.9 and 1.2 mm Hg lower for SBP and DBP, respectively, as compared with the auscultatory measurement used in the United States reference[9] and number of BP measurements taken to analysis—in the OLA study, we analysed the mean of second and third measurement, which is on average 1–2 mm Hg lower compared with the first BP reading used for the construction of BP percentiles in the United States BP reference.[1] However, in the OLA study, German and European children BP references were developed using oscillometric BP measurement. It is necessary to take into consideration the fact that the Polish and German blood pressure measurements were carried out using the same oscillometric device validated in children (Datascope Accutorr Plus). In turn, in IDEFICS references, the BP was measured using another automated oscillometric device (Welch Allyn 4200B-E2). Oscillometric devices are becoming more popular for BP measurement in the clinics. Furthermore, better co-operation from small children is more likely as the oscillometric device may be applied. Both the United States and Germany referential data papers do not provide information on the exclusion of children from the analysis due to excessive movement and/or crying

Table 4. Blood pressure percentiles for preschool boys and girls by age and height, quantile regression models

Age	*Height (cm)*	*SBP (mm Hg)*							*MAP (mm Hg)*							*DBP (mm Hg)*						
		1st	*5th*	*10th*	*50th*	*90th*	*95th*	*99th*	*1st*	*5th*	*10th*	*50th*	*90th*	*95th*	*99th*	*1st*	*5th*	*10th*	*50th*	*90th*	*95th*	*99th*
Boys																						
3	91.4	77	80	81	90	100	102	107	54	59	61	67	75	78	83	38	44	46	53	61	63	71
	92.7	77	80	82	91	100	103	108	55	59	61	68	75	78	84	39	44	46	53	61	64	71
	95.0	78	81	83	91	101	104	109	56	60	62	68	76	79	85	39	44	46	54	62	64	72
	97.5	78	82	84	92	102	105	111	57	61	62	69	76	80	86	39	44	47	54	62	65	73
	100.0	79	83	85	93	103	106	113	58	61	63	69	77	81	87	39	45	47	55	63	66	74
	102.3	79	83	85	94	104	107	114	58	62	63	70	78	82	88	40	45	47	55	63	67	75
	103.7	79	84	86	94	104	108	115	59	62	64	70	78	82	89	40	45	48	55	64	67	75
4	98.2	78	81	82	91	102	104	108	55	60	61	68	76	79	84	40	44	46	54	61	64	70
	99.7	78	81	83	92	102	104	109	56	60	62	68	76	79	84	40	44	46	54	62	64	70
	102.2	78	82	84	92	103	105	111	56	61	62	69	77	80	85	40	45	47	54	62	65	71
	104.9	79	83	85	93	104	107	113	57	61	63	70	77	81	86	40	45	47	55	63	66	72
	107.7	79	84	86	94	104	108	114	58	62	63	70	78	82	87	40	45	48	55	64	67	73
	110.2	79	84	86	95	105	109	116	59	62	64	71	79	82	88	41	46	48	56	64	67	74
	111.7	80	85	87	95	106	109	117	60	63	64	71	79	83	89	41	46	48	56	64	68	75
5	104.3	78	82	83	92	103	105	110	56	60	62	69	77	79	84	41	45	47	54	62	65	69
	106.0	78	82	84	93	103	106	111	56	61	62	69	77	80	84	41	45	47	54	62	65	70
	108.8	79	83	85	93	104	107	112	57	61	63	70	78	81	85	41	45	47	55	63	66	71
	111.8	79	84	86	94	105	108	114	58	62	63	70	78	82	87	41	46	48	55	64	66	71
	114.9	79	84	87	95	106	109	116	59	62	64	71	79	83	88	42	46	48	56	64	67	72
	117.6	80	85	87	96	107	110	118	60	63	64	71	80	83	89	42	46	49	56	65	68	73
	119.3	80	85	88	96	107	111	119	61	63	65	72	80	84	89	42	46	49	57	65	68	74
6	110.2	78	82	84	93	105	107	111	57	61	63	70	78	80	84	42	46	47	55	63	65	68
	112.0	79	83	85	94	105	108	112	57	61	63	70	78	81	85	42	46	47	55	63	66	69
	115.0	79	84	86	94	106	109	114	58	62	63	71	79	82	86	42	46	48	56	64	66	70
	118.4	79	84	87	95	107	110	116	59	62	64	71	79	83	87	42	46	48	56	64	67	71
	121.8	80	85	88	96	107	111	118	60	63	65	72	80	83	88	43	47	49	56	65	68	72
	124.8	80	86	88	97	108	112	119	61	63	65	72	81	84	89	43	47	49	57	66	69	73
	126.6	81	86	89	97	109	113	120	61	64	65	73	81	85	89	43	47	49	57	66	69	73
Girls																						
3	90.0	76	80	82	91	101	104	112	54	59	62	68	77	78	84	39	43	46	54	63	66	73
	91.4	77	81	83	92	102	104	112	55	59	62	69	77	79	84	39	44	46	54	63	66	72
	93.7	77	81	83	92	103	105	112	55	60	62	69	78	80	85	39	44	46	55	63	66	72
	96.3	78	82	84	93	104	106	112	56	60	63	70	78	80	85	39	44	47	55	64	66	72
	98.9	79	83	85	94	105	108	112	57	61	63	70	79	81	85	39	44	47	55	64	66	71
	101.2	80	83	85	94	106	109	112	58	61	63	71	79	82	85	38	45	48	56	64	67	71
	102.6	81	84	86	95	107	109	113	58	61	63	71	80	82	86	38	45	48	56	64	67	71
4	96.8	77	81	83	92	102	105	114	55	60	62	69	77	79	86	40	44	46	55	63	66	74
	98.3	77	82	84	93	103	105	114	56	60	63	69	78	80	86	40	45	47	55	64	67	73
	100.9	78	82	84	93	104	107	114	57	61	63	70	78	81	86	40	45	47	55	64	67	73
	103.7	79	83	85	94	105	108	114	57	61	63	70	79	81	86	40	45	48	56	64	67	73
	106.5	80	84	86	95	106	109	114	58	62	64	71	80	82	87	40	45	48	56	65	67	72
	109.0	81	84	86	95	107	110	115	59	62	64	71	80	83	87	40	46	48	56	65	67	72
	110.5	81	85	87	96	108	111	115	59	62	64	72	81	83	87	40	46	49	57	65	68	72
5	103.0	77	83	84	93	103	106	116	57	61	63	70	78	80	87	42	45	47	55	64	67	75
	104.6	78	83	85	94	104	107	116	57	61	63	70	78	81	87	42	45	48	55	64	67	74
	107.4	79	84	85	94	105	108	116	58	62	64	71	79	81	87	41	46	48	56	65	68	74
	110.5	80	84	86	95	106	109	116	59	62	64	71	80	82	88	41	46	48	56	65	68	74
	113.6	81	85	87	96	107	110	117	59	63	64	72	80	83	88	41	46	49	57	65	68	73
	116.4	81	86	87	96	108	111	117	60	63	65	72	81	84	88	41	46	49	57	66	68	73
	118.1	82	86	88	97	109	112	117	61	63	65	72	81	84	88	41	47	50	57	66	68	73
6	108.7	78	84	85	94	104	107	118	58	62	64	71	79	81	88	43	46	48	56	65	68	76
	110.6	79	84	86	95	105	108	118	58	62	64	71	79	82	88	43	46	48	56	65	68	75
	113.6	79	85	86	95	106	109	118	59	63	64	71	80	82	89	43	47	49	56	65	68	75
	117.0	80	85	87	96	107	110	118	60	63	65	72	80	83	89	43	47	49	57	65	68	75
	120.4	81	86	88	97	108	112	119	61	64	65	72	81	84	89	42	47	50	57	66	69	74
	123.4	82	87	88	97	109	113	119	61	64	66	73	82	85	90	42	47	50	58	66	69	74
	125.2	83	87	89	98	110	113	119	62	64	66	73	82	85	90	42	48	50	58	66	69	74

Abbreviations: DBP, diastolic blood pressure; MAP, mean arterial blood pressure; SBP, systolic blood pressure.

Table 5. Comparison of observed (obs.) versus expected (exp.) frequencies (1, 4, 5, 40, 40, 5, 4 and 1%) of blood pressure in the sample relative to QR-fitted percentiles: chi-square goodness-of-fit test results

Percentile band	*SBP*			*DBP*			*MAP*		
	N	*% obs.*	*% exp.*	N	*% obs.*	*% exp.*	N	*% obs.*	*% exp.*
Boys									
< 1	22	1.02	1.00	22	1.02	1.00	21	0.99	1.00
1–4.9	84	3.91	4.00	85	3.96	4.00	85	4.00	4.00
5–9.9	110	5.12	5.00	107	4.98	5.00	105	4.94	5.00
10–49.9	858	39.93	40.00	860	40.02	40.00	851	40.05	40.00
50–89.9	860	40.02	40.00	860	40.02	40.00	850	40.00	40.00
90–94.9	108	5.03	5.00	109	5.07	5.00	107	5.04	5.00
95–98.9	85	3.96	4.00	84	3.91	4.00	84	3.95	4.00
⩾99	22	1.02	1.00	22	1.02	1.00	22	1.04	1.00
	Chi-Sqr = 0.146; p = 1;			Chi-Sqr = 0.104; p = 1;			Chi-Sqr = 0.062; p = 1;		
Girls									
< 1	23	1.03	1.00	22	0.99	1.00	21	0.95	1.00
1–4.9	87	3.90	4.00	89	3.99	4.00	89	4.03	4.00
5–9.9	113	5.07	5.00	112	5.02	5.00	110	4.98	5.00
10–49.9	891	39.97	40.00	892	40.02	40.00	884	40.00	40.00
50–89.9	892	40.02	40.00	889	39.88	40.00	886	40.09	40.00
90–94.9	111	4.98	5.00	113	5.07	5.00	109	4.93	5.00
95–98.9	90	4.04	4.00	89	3.99	4.00	88	3.98	4.00
⩾99	22	0.99	1.00	23	1.03	1.00	23	1.04	1.00
	Chi-Sqr = 0.111; *P* = 1;			Chi-Sqr = 0.059; *P* = 1;			Chi-Sqr = 0.124; *P* = 1;		

Abbreviations: DBP, diastolic blood pressure; MAP, mean arterial blood pressure; QR, quantile regression; SBP, systolic blood pressure.

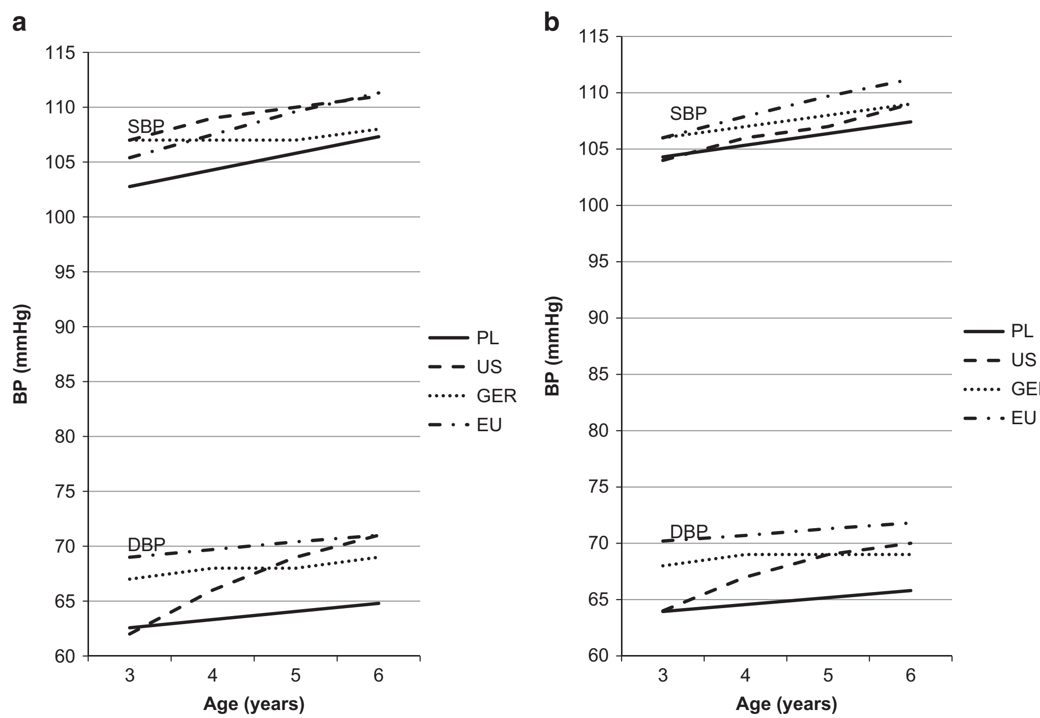

Figure 1. Comparison of the 90th SBP and DBP percentiles. PL = OLA study; US;[1] GER;[18] EU.[19] (**a**) Boys. (**b**) Girls. EU, European; GER, German; US, United States.

behaviour. Second, the fourth report analysed BP values obtained during the first measurement, whereas in the German study, the BP was measured twice and in IDEFICS study two recordings were taken and a third in case of a > 5% difference between the first and second measurement. The average of two or three measurements was analysed. On the contrary, in the OLA study, an average of second and third measurements was analysed. The number and order of measurements may partly contribute to the differences in BP references, because it has been shown that the average of first and second BP measurements is higher than the average of the second and third measurements.[7] In addition, the differences in reported BP measurements between studies may be attributable to population differences, such as genetic or environmental factors, which cannot be delineated in this study. It is worth noting, however, that our study together with the KiGGS and IDEFICS studies might be useful for European countries to consider

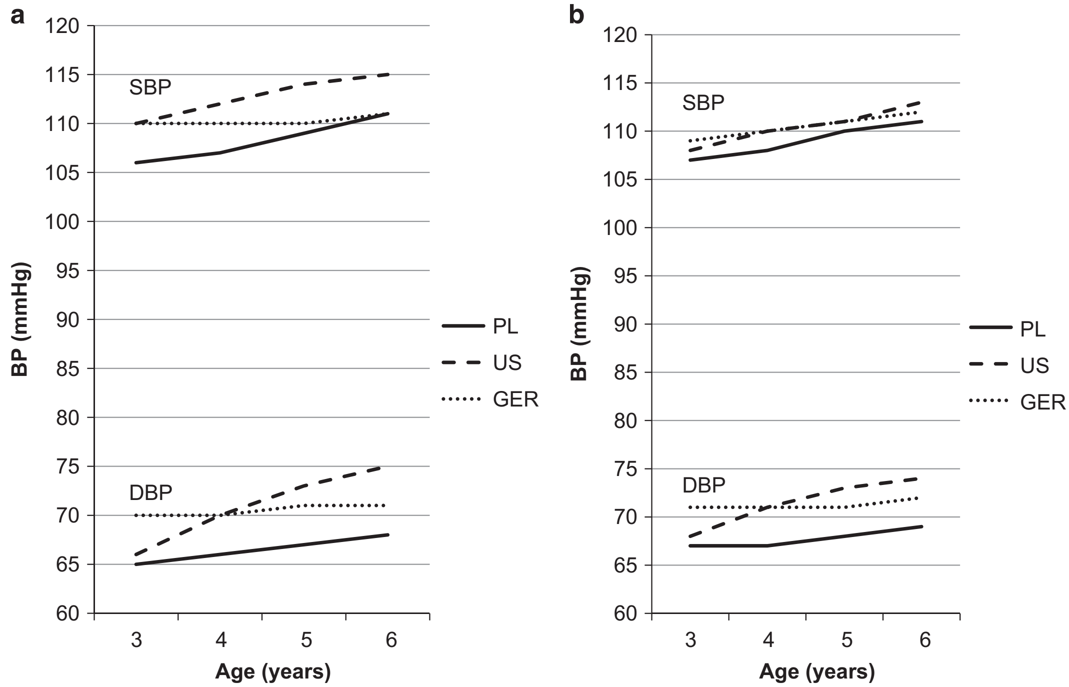

Figure 2. Comparison of the 95th SBP and DBP percentiles. PL = OLA study; US;[1] GER.[18] (**a**) Boys. (**b**) Girls. GER, German; US, United States.

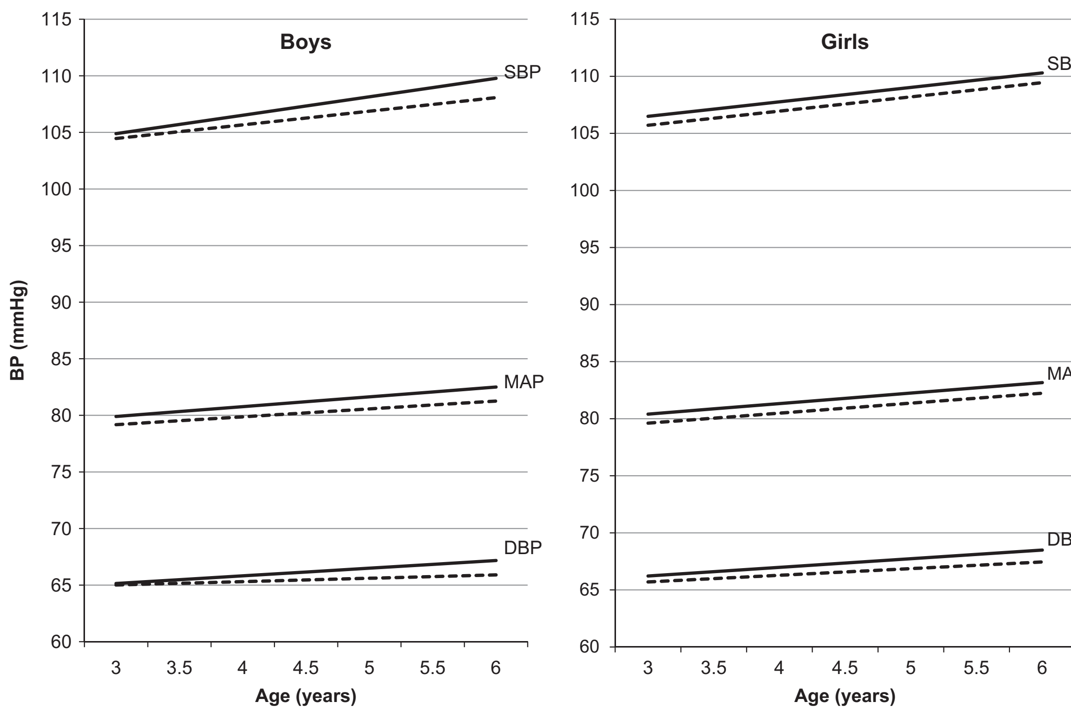

Figure 3. Comparison of 95th blood pressure percentile for median height between OLA reference sample (solid line) and OLA non-overweight sample (dashed line).

that their population may differ demographically and genetically from reference ranges based on other populations.

Classification of BP status according to the fourth Task Report and the European Society of Hypertension guidelines is based on cut-off points for SBP and/or DBP. We also present the percentiles of mean arterial pressure. A 'Gold standard' BP measurement is still based on an auscultatory measurement. However, it should be noted that at the present, the diagnosis of arterial hypertension is usually confirmed by ambulatory blood pressure monitoring. Moreover, most ambulatory blood pressure monitoring devices measure BP using oscillometric method. Oscillometric method determines MAP at a point of maximum oscillation of the arterial wall while decreasing cuff pressure. SBP and DBP are calculated relative to MAP according to the manufacturer's proprietary algorithm. For this reason, we considered the presentation of MAP percentiles of ambulatory BP readings to be of importance for clinical assessment of BP in children. Comparison of BP percentiles fitted with the use of samples with and without overweight children showed differences in SBP, DBP and MAP percentiles, which were slight for the median, increasing with higher BP percentiles and more pronounced with increasing age and height. Although our analysis showed slight differences in SBP, DBP and MAP percentiles between total sample (including overweight subjects) and the sample limited to the non-overweight children, it should be noted that assessing paediatric weight and applying the definition of overweight is not straightforward, particularly in a population of the youngest (preschool) children.[24] There are differences between applicable categories of overweight. In our analysis, we used standard criteria adopted by International Obesity Task Force. Neuhauser *et al*.[18] used German reference system by Kromeyer-Hauschild *et al*.[25] where BMI > 90th percentile (for gender and age) was categorised as overweight. Small differences between BP percentiles developed for the general population and for normal-weight children aged 3–6 years and lack of uniform cut-off points for defining overweight in children suggests that in preschool children, the BP references calculated from general population sample may be used.

In conclusion, we present oscillometric BP references for preschool children based on data obtained from representative sample of children aged 3–6 years and fitted using the QR model, which offered flexibility and good fit model. We found differences between the OLA study and the fourth report, German and the IDEFICS study references.

Limitation of the study

Uncertainty as to the early childhood overweight and obesity definition.
Lack of significance testing of differences in the comparison of the 90th and 95th SBP and DBP reference percentiles for the corresponding height with the United States, German and IDEFICS study BP references.

Strengths of the study

Large, nationally representative sample of preschool children.
Use of a validated oscillometric device to measure BP.
Robust statistical methods to construct BP percentiles and enabling conversion to BP *z*-score.
Statistically confirmed percentile fit.

What is known about this topic?

- Paediatric United States blood pressure references based on the auscultatory measurement are widely used internationally.
- The United States references may not fit other populations.

What this study adds?

- Age- and height-specific blood pressure references for Polish preschool children were developed in a nationally representative sample based on measurements with the use of a validated oscillometric device and up-to-date statistical methods.
- Polish preschool children's BP percentiles are lower than those from the current United States, German and European references.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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