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Original Article (Pages: 2153-2166)

Blood Pressure Nomograms by Age and Weight for Iranian Children and Adolescents

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Abstract

Background: Normal standard references of blood pressure (BP) for children and adolescents have been suggested to be constructed based on anthropometric indices. Accordingly, we aimed to develop first BP reference percentiles by weight and age for Iranian children aged 3-18 years old.

Materials and Methods: A total of 16,246 children and adolescents aged 3-18 years were included from 3 cross-sectional studies conducted in Tehran- Iran. Data on demographic characteristics, anthropometric indices and BP values of these subjects were gathered. Quantile regression model was used to assess the need for weight adjustment in different percentiles of systolic and diastolic BPs with age, gender, and the corresponding weight percentiles. Then, Age- and sex-specific BP nomograms were developed according to weight.

Results: All the regression coefficients for weight percentiles were statistically significant in quantile regression of BPs, which confirms the positive effect of adjustment for weight (P<0.05). The BP percentiles by age and weight are presented for each gender. All the BP percentiles rose steadily in all the weight percentiles with minor discrepancies between the two genders. Based on the weight-adjusted BP curves, lean subjects are estimated to have a higher prevalence of hypertension while this figure is lower among the overweight and obese children.

Conclusion: This study presents the first Iranian BP references by age and weight for 3 to 18 year old children and adolescents. BMI-adjusted BP curves were found to be a better tool for assessing the prevalence of hypertension in children and adolescents, on the basis of which a more reliable classification standard for hypertension could be obtained.

Key Words: Blood Pressure, Children, Nomograms, References, Weight.

*Please cite this article as: Hosseini M, Baikpour M, Yousefifard M, Yaseri M, Fayaz M, Shirafkan H, et al. Blood Pressure Nomograms by Age and Weight for Iranian Children and Adolescents. Int J Pediatr 2016; 4(7): 2153-66.

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Received date Feb23, 2016; Accepted date: Mar 22, 2016

1- INTRODUCTION

Approximately, 13.5% of the premature deaths and 6% of the total global Disability Adjusted Life Year is attributed to hypertension which is regarded as one of the most prevalent risk factors of cardiovascular diseases (1). Accordingly high blood pressure (BP) among adults and children has drawn major attention and this health issue is considered as a priority for the health-care systems all around the world. Hypertension is associated with various complications which can be controlled with early detection and treatment of the patients, therefore blood pressure measurement is now established as an integral part of routine physical examinations (2).

Cardiovascular accidents most commonly occur in patients older than fifty years; however, epidemiologic and pathophysiologic evidence suggest that high blood pressure and other risk factors of cardiovascular disease develop from childhood (3). Furthermore, a strong relation has also been found between high levels of blood pressure in childhood and adulthood hypertension (4-6). In this regard, many researchers have aimed to assess blood pressure trends in children and adolescents.

On another note, BP has been observed to vary among different ethnicities and races (7-10) and so standard nomograms derived from one population might not be applicable for others and local data should be referred to instead (9-12). Accordingly, BP nomograms for children and adolescents up to the age of 18 are presented by the United States' Task Force on BP Control in Children (13-15). Similar reference data have been presented by other countries as well (7, 8, 10, 16, 17). Few studies have developed references of systolic and diastolic BPs for children and adolescents in Iran (18-21), of which only the study of Ataei et al. was representative for the whole population of the country and included all the age range of childhood and adolescence (22). Only BP percentiles by age and height were presented in their study, but since the correlation of BP has been found to be stronger with weight and body mass index (BMI) rather than height (23-25), for the first time in Iran, we aimed to develop BP percentiles by weight for these age groups.

2- MATERIALS AND METHODS

2-1. Study design

The present study was performed based on data gathered from three surveys conducted during 2000 to 2010 in Tehran, the capital city of Iran. The protocol of the study was approved by the Ethics Committee of Tehran University of Medical Sciences and principles of the Helsinki declaration were followed throughout the survey.

2-2. Study Population

A total of 16,246 children and adolescents aged 3 to 18 years old were included in this study, a sample population chosen from Tehran previously shown to be representative of the entire Iranian (26, 27). In one of these studies, it was shown that standard body mass index percentiles drawn based on data from Tehran did not show a significant difference with standard curves drawn based on data from the entire country (27). Data gathered by three cross-sectional studies were combined to make our sample population. Randomized sampling of all these three surveys had been carried out from 20 different districts of Tehran. Conducted during November 2000 to November 2002, the first survey included 8,848 primary school children aged 7 to 12 years old. The second study was carried out in 2004 and sampled 6,017 children and adolescents aged 12 to 18 years old from secondary and high schools. The last study applied a 2-stage cluster sampling method in 2010 to include 2,107 subjects which comprised of 1 month to 2 years old infants and 2 to 7 years old children from kindergartens (28). Due to low sample size in ages 1 month to 2 years old, in the present study, we included children and adolescents aged 3-18 years old.

A child with a normal general appearance, no documented underlying disease, no history of cardiovascular disorders and no history of antihypertensive drug use was regarded as a healthy child, which was established as the inclusion criterion for this study. Detailed explanations of the sampling methods are presented in our previous articles (19, 28, 29). Briefly, 20 districts were selected based on municipal districts of Tehran. In each district, 1 all-girls school and 1 all-boys school were randomly selected from the schools listed by Tehran education office. In each school, all the students were studied.

Data were collected by the trained interns of the medical center. The parents or guardians of the subjects signed an informed written consent prior to inclusion.

2-3. Measurements

Weight measurements were done by a group of trained field technicians in each administrative district. A SECA scale (USA, model 760) was used to weigh children aged 3 to 6 years old with an accuracy of 500 grams. School-aged children were weighed without shoes and heavy outer clothing via a daily calibrated SECA balanced scale (Germany, model 710). Detailed descriptions of the BP massurments are presented in previous studies (22). Briefly, BP was measured via a standard mercury sphygmomanometer (Model 1002/ Presameter, Riester, Germany) with the child awake, after at least 5 minutes rest in a comfortable sitting position. The cuff was chosen in a way that its bladder covered 80%–100% of the right arm circumference and its width covered approximately 40% the arm length, so that the antecubital fossa would be free for auscultation. Systolic and diastolic BPs were recorded based on Korotkoff sounds (the K1 sound for systolic BP, the K4 and K5 sounds for diastolic BP of 3-12 year olds and K5 for 13-18 year old children, respectively). The mean of two consecutive BP measurements, measured at least 30 seconds apart, was calculated for each subject.

2-4. Statistical analysis

2-4-1. Age-gender-specific percentile values

To assess the correlation between weight, blood pressure and age, the age-sex-specific normal deviations of weight was calculated. Then, the computed normal deviation was mounted in the standard normal distribution and the corresponding percentile value was calculated to develop the age-sex-specific percentile values of weight.

2-4-2. Construction of the BP nomograms according to age, gender and weight

BP percentiles were presented as a function of age and weight through construction of two gender-specific separate models for systolic BP and diastolic BP. First, the weight percentiles were modeled with age for both genders using latent moderated structural (LMS) equations method (30). Then an extension of this method developed for two covariates was used to simultaneously fit the reference curves for by age and weight. The free R 2.15.2 statistical software (http://www.R-project.org) was used to fit the Generalized Additive Models for Location Scale and Shape (GAMLSS) with the Box-Cox-Cole-Green distribution family (31-33). The modeling procedure is further explained in the study of Ataei et al. (22). The goodness of fit was assessed through evaluating the generalized Akaike information criterion and the proportion of data outside the smoothed percentiles.

Moreover, to assess the effect of weight on diagnosis of hypertension, the prevalence of hypertension was calculated in three groups of lean, average, and overweight and obese children (<25th, 25th-75th, and >75th percentiles of BMI, respectively) using the 95th percentile of weight adjusted BP references and the figures were then compared to the method proposed by the Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents criteria, that applies the 95th percentile of unadjusted BP references (34). Finally, the fitted percentile curves were compared with the reference values developed by USA (13), Germany (17), Turkey (10), Great Britain (8), China (16), and Saudi Arabia (7).

3- RESULTS

A total of 8,381 (51.59%) boys and 7,865 (48.41%) girls aged 3–18 years were included and their BPs and weights were measured. Demographic characteristics of the included subjects are presented in **Table. 1**. As demonstrated, in all age groups the mean of weight and height for boys was higher than girls. The discrepancies between the two measurements of BP were not significant (P>0.05). The average of absolute differences for boys ranged from 0.22 to 1.48 mmHg and among girls varied from 0.3 to 1.58 mmHg. Accordingly, the average of the two values for each subject was calculated and included in the analysis. The mean of diastolic and systolic BPs for boys was higher than girls, in almost all the age groups, except for the SBP in age group of 7-12 years where girls present with a slightly higher average.

Quantile regression models were utilized for different percentiles of BPs with age, gender and the corresponding weight percentile to assess the need for weight adjustment. As presented in **Table.2**, the P- values calculated were found to be less than 0.001, which confirms the positive effect of adjustment for weight. BP percentiles for boys and girls according to age and weight are presented in **Tables.3 and 4**. The 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles of weight are given in kilograms. As can be seen, all the SBP percentiles rose steadily in all the weight percentiles of both genders. In earlier ages, the SBP values among boys are slightly higher than girls, but the differences decrease in a way that the figures approximate each other in the two genders and stay steady from the age 5 through 12 years old.

After the age of 12 the curves diverge again and the values among boys rise persistently while the increasing trend of SBP values among girls slows down. DBP values among girls were slightly higher than boys before the age of 5, and from that point on through the age of 8 the values were nearly similar in both genders. The curves start to part again from the age of 8 and the DBP percentiles for girls remain higher than the values for boys with smaller divergences compared to SBP curves. The prevalence of hypertension estimated based on the standard curves of BP adjusted by anthropometric indices is a better indicator of this disorder in the population. Therefore, we aimed to estimate the prevalence of hypertension based on weight-adjusted BP values in the three BMI categories. The figures using the US references presented in the fourth task force report for subjects with BMIs in the <25th, 25th-85th, and >85th percentiles were calculated to be 3.56, 7.0 and 12.90% for girls and 3.10, 3.85, and 10.17% for boys, respectively. But using weight-adjusted BP percentiles, the prevalence of hypertension for the mentioned BMI categories were found to be 8.08, 8.35, and 6.91% for girls and 9.76, 6.60, and 7.80% for boys, respectively. As can be seen, the prevalence of hypertension was estimated to be higher among the lean subjects and lower, among the overweight and obese children when the weight-adjusted standard curves of BPs are used instead of unadjusted BP references. Therefore, adjustment of these curves according to weight decreased the false negative cases in lean subjects and false positive cases among overweight and obese children and adolescents (**Figure.1**).

Table-1: Baseline characteristics of the included children and adolescents (8381 boys and 7865 girls aged 3–18 years)

Subjects' characteristics	Age groups (year)		
	3-6	7-12	13-18
Number of children			
Boys	746	4505	3130
Girls	635	4698	2532
Mean (±standard deviation) of weight (kg)			
Boys	16.96 (4.06)	29.50 (8.38)	58.33 (15.15)
Girls	15.86 (3.50)	27.73 (7.92)	48.28 (11.51)
Mean (±standard deviation) systolic blood pressure			
Boys	93.56 (10.24)	107.24 (8.98)	115.35 (11.51)
Girls	91.50 (8.79)	107.45 (8.90)	108.97 (10.66)
Mean (±standard deviation) diastolic blood pressure			
Boys	55.35 (9.61)	63.69 (9.49)	72.41 (7.87)
Girls	54.41 (8.48)	63.34 (9.57)	71.21 (9.11)

Table-2: Estimated quintile regression for blood pressure measurements according to age and weight percentile and gender

Parameters	25th		50th		75th / 85th		95h	
	Coeff (±SE)	P-value	Coeff (±SE)	P-value	Coeff (±SE)	P-value	Coeff (±SE)	P-value
Systolic Blood Pressure								
Age (years)	1.34 (±0.03)	<0.001	1.42 (±0.02)	<0.001	1.53 (±0.02)	<0.001	1.87 (±0.03)	<0.001
Gender	-1.49 (±0.21)	<0.001	-1.45 (±0.17)	<0.001	-1.00 (±0.17)	<0.001	0.05 (±0.25)	0.84
Weight (Percentile)	0.08 (±0.003)	<0.001	0.07 (±0.003)	<0.001	0.06 (±0.003)	<0.001	0.09 (±0.004)	<0.001
Intercept	84.7 (±0.40)	<0.001	90.9 (±0.30)	<0.001	95.6 (±0.29)	<0.001	96.9 (±0.40)	<0.001
R^2	0.1467		0.1569		0.1892		0.2428	
Diastolic Blood Pressure								
Age (years)	1.50 (±0.03)	<0.001	1.42 (±0.02)	<0.001	1.43 (±0.02)	<0.001	1.53 (±0.03)	<0.001
Gender	0.14 (±0.21)	0.495	0.04 (±0.18)	0.849	0.04 (±0.12)	0.001	1.13 (±0.18)	<0.001
Weight (Percentile)	0.06 (±0.003)	<0.001	0.06 (±0.003)	<0.001	0.04 (±0.002)	<0.001	0.04 (±0.003)	<0.001
Intercept	41.7 (±0.37)	<0.001	48.9 (±0.32)	<0.001	54.2 (±0.20)	<0.001	57.7 (±0.33)	<0.001
R^2	0.1688		0.1780		0.2104		0.2428	

R^2: Coefficient of determination; SE: Standard error; All coefficients (Coeff) for weight percentiles are statistically significant at P < 0.001.

Table- 3: Blood pressure values for boys according to age and weight

Age (Year)	Weight (kg)	SBP (mm Hg)				DBP (mm Hg)			
		50th Percentile (Median)	90th Percentile	95th Percentile	99th Percentile	50th Percentile (Median)	90th Percentile	95th Percentile	99th Percentile
3	8.4	81	90	92	97	48	57	59	63
3	9	82	91	93	97	48	57	59	63
3	10.1	83	92	94	99	49	58	60	64
3	11.4	84	94	96	101	49	58	60	64
3	12.9	86	95	98	103	50	59	61	65
3	14.4	88	97	100	104	50	60	62	66
3	15.3	89	98	101	106	51	60	62	67
4	10.2	86	96	98	103	51	60	62	66
4	10.9	87	96	99	104	51	60	63	67
4	12.2	88	98	100	105	52	61	63	67
4	13.8	90	100	102	107	52	62	64	68
4	15.6	92	101	104	109	53	62	65	69
4	17.5	93	103	106	111	54	63	66	70
4	18.8	94	105	108	113	54	64	66	70
5	11.9	91	101	103	108	53	63	65	69
5	12.7	91	101	104	109	54	63	65	69
5	14.1	93	103	105	110	54	64	66	70
5	16	94	104	107	112	55	64	67	71
5	18.2	96	106	109	114	56	65	68	72
5	20.5	98	108	111	117	57	66	69	73
5	22.1	99	110	113	118	57	67	69	74
6	13.5	94	105	107	112	56	65	67	71
6	14.4	95	105	108	113	56	65	68	72
6	16	96	107	109	114	57	66	68	72
6	18.1	98	108	111	116	57	67	69	73
6	20.7	100	110	113	118	58	68	70	74
6	23.4	101	112	115	121	59	69	71	76
6	25.3	103	114	117	122	60	69	72	76
7	15.1	98	108	111	116	58	67	69	73
7	16	98	109	111	117	58	67	70	74
7	17.8	99	110	113	118	59	68	70	74
7	20.1	101	111	114	120	59	69	71	75
7	23.1	102	113	116	122	60	70	72	77
7	26.3	104	115	118	124	61	71	73	78
7	28.5	106	117	120	125	62	72	74	79
8	16.7	100	111	114	119	59	69	71	75
8	17.7	101	111	114	119	60	69	71	76
8	19.7	102	112	115	121	60	70	72	76
8	22.3	103	114	117	122	61	70	73	77
8	25.6	105	116	119	124	62	71	74	78
8	29.3	107	118	121	126	63	73	75	80
8	32	108	119	122	128	64	74	76	81
9	18.6	103	113	116	121	61	70	73	77
9	19.7	103	114	117	122	61	71	73	77
9	21.9	104	115	118	123	62	71	74	78
9	24.9	105	116	119	125	63	72	74	79
9	28.6	107	118	121	127	64	73	76	80
9	32.9	109	120	123	129	65	74	77	81
9	36	110	121	124	130	66	75	78	82
10	20.8	104	115	118	124	63	72	74	78
10	22.1	105	116	119	124	63	72	74	79
10	24.5	106	117	120	125	64	73	75	79
10	27.9	107	118	121	127	64	74	76	80
10	32.1	109	120	123	128	65	75	77	81
10	37	110	122	125	130	67	76	79	83
10	40.7	111	123	126	132	67	77	80	84
11	23.4	106	117	120	125	64	73	76	80
11	24.8	106	117	120	126	65	74	76	80
11	27.6	107	118	121	127	65	74	77	81
11	31.4	108	120	123	128	66	75	77	82
11	36.2	110	121	124	130	67	76	79	83
11	41.9	112	123	126	132	68	78	80	84
11	46	113	124	127	133	69	79	81	85
12	26.3	107	118	121	126	66	75	77	81
12	28	108	119	122	127	66	75	77	81
12	31.1	109	120	123	128	67	76	78	82
12	35.4	110	121	124	129	68	77	79	83

12	41	111	122	125	131	69	78	80	84
12	47.5	113	124	127	133	70	79	81	86
12	52.3	114	125	129	134	71	80	82	87
13	29.7	108	119	122	128	67	76	78	82
13	31.5	109	120	123	128	68	76	79	83
13	35.1	110	121	124	129	68	77	79	83
13	40.1	111	122	125	131	69	78	80	84
13	46.4	112	124	127	132	70	79	81	86
13	53.9	114	125	128	134	71	80	83	87
13	59.4	115	126	130	135	72	81	84	88
14	33.3	109	120	123	129	69	78	80	84
14	35.4	110	121	124	129	69	78	80	84
14	39.5	111	122	125	130	70	78	81	85
14	45.1	112	123	126	132	71	79	82	86
14	52.3	114	125	128	134	72	80	83	87
14	60.7	115	127	130	136	73	82	84	88
14	67	116	128	131	137	74	83	85	89
15	36.9	111	121	124	130	71	79	81	85
15	39.3	111	122	125	131	71	79	81	85
15	43.9	112	123	126	132	71	80	82	86
15	50.3	114	125	128	133	72	81	83	87
15	58.4	115	127	130	135	73	82	84	88
15	67.9	117	129	132	137	74	83	85	89
15	74.8	118	130	133	139	75	84	86	90
16	40.5	112	123	126	131	72	80	82	86
16	43.2	113	124	127	132	72	80	83	87
16	48.4	114	125	128	134	73	81	83	87
16	55.5	115	127	130	135	73	82	84	88
16	64.5	117	129	132	138	74	82	85	89
16	75	119	131	134	140	75	83	86	90
16	82.7	121	132	136	142	76	84	87	91
17	44.1	113	124	127	133	73	81	83	87
17	47.1	114	125	128	134	73	82	84	88
17	52.8	116	127	130	136	74	82	84	88
17	60.6	118	129	132	138	74	82	85	89
17	70.6	120	132	135	141	75	83	85	89
17	82.1	122	134	138	144	76	84	86	90
17	90.6	124	136	139	145	76	85	87	91
18	47.6	115	126	129	135	74	82	84	88
18	50.8	116	127	131	136	75	83	85	88
18	57.1	118	130	133	138	75	83	85	89
18	65.7	121	132	135	141	75	83	85	89
18	76.6	124	136	139	145	76	84	86	90
18	89.2	127	139	142	148	76	84	86	90
18	98.4	129	141	144	151	76	85	87	91

Weight in kilograms for each age represents the 5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 95^{th} percentile.

Table 4: Blood pressure values for girls according to age and weight

Age (Year)	Weight (kg)	SBP (mm Hg)				DBP (mm Hg)			
		50^{th} Percentile (Median)	90^{th} Percentile	95^{th} Percentile	99^{th} Percentile	50^{th} Percentile (Median)	90^{th} Percentile	95^{th} Percentile	99^{th} Percentile
3	7.4	81	89	92	96	47	55	57	61
3	8	81	90	92	97	47	56	58	61
3	9.1	82	91	94	98	48	56	58	62
3	10.4	83	92	95	99	49	57	59	63
3	11.9	85	94	96	101	50	58	60	64
3	13.5	86	96	98	103	51	59	62	65
3	14.5	87	97	99	104	51	60	62	66
4	8.7	86	95	97	102	50	58	60	64
4	9.3	86	96	98	103	50	59	61	65
4	10.6	87	97	99	104	51	59	62	66
4	12.1	89	98	101	105	52	60	63	67
4	14	90	100	102	107	53	62	64	68
4	16	92	101	104	109	54	63	65	69
4	17.3	93	102	105	110	54	64	66	70
5	10	90	100	103	107	52	61	63	67
5	10.8	91	100	103	108	53	61	64	68
5	12.2	92	101	104	109	53	62	65	69
5	14.1	93	103	106	111	54	63	66	70
5	16.3	94	105	107	113	55	64	67	71

5	18.7	96	106	109	114	56	66	68	72
5	20.3	97	108	110	116	57	67	69	73
6	11.5	94	104	107	112	55	63	66	70
6	12.4	95	105	108	113	55	64	66	70
6	14.1	96	106	109	114	56	65	67	71
6	16.3	97	107	110	115	57	66	68	72
6	18.9	98	109	112	117	58	67	69	74
6	21.7	100	111	114	119	59	68	71	75
6	23.7	101	112	115	120	60	69	72	76
7	13.2	98	108	111	116	57	66	68	72
7	14.2	98	109	111	117	57	66	68	73
7	16.1	99	109	112	118	58	67	69	74
7	18.6	100	111	114	119	59	68	70	75
7	21.7	102	112	115	121	60	69	72	76
7	25	103	114	117	123	61	71	73	78
7	27.3	104	116	119	124	62	72	74	79
8	15.1	101	111	114	120	59	68	70	74
8	16.2	101	112	115	120	59	68	71	75
8	18.3	102	113	116	121	60	69	71	76
8	21.2	103	114	117	123	61	70	73	77
8	24.7	104	115	119	124	62	71	74	78
8	28.5	106	117	120	126	63	73	75	80
8	31.2	107	118	122	127	64	74	76	81
9	17.2	103	114	117	123	60	70	72	76
9	18.4	103	114	117	123	61	70	73	77
9	20.8	104	115	118	124	62	71	73	78
9	24	105	116	119	125	63	72	75	79
9	28	107	118	121	127	64	73	76	80
9	32.4	108	120	123	129	65	75	77	82
9	35.5	109	121	124	130	66	76	78	83
10	19.5	105	116	119	125	62	72	74	78
10	20.9	105	116	119	125	63	72	74	79
10	23.6	106	117	120	126	63	73	75	80
10	27.2	107	118	121	127	64	74	76	81
10	31.7	108	120	123	129	65	75	78	82
10	36.8	110	121	125	131	67	77	79	84
10	40.3	111	123	126	132	67	77	80	85
11	22.2	106	117	120	126	64	73	76	80
11	23.8	107	118	121	127	64	74	76	81
11	26.8	107	118	122	127	65	75	77	81
11	30.8	108	119	123	129	66	76	78	83
11	35.9	109	121	124	130	67	77	80	84
11	41.6	111	123	126	132	68	78	81	85
11	45.6	112	124	127	133	69	79	82	86
12	25.2	107	118	121	127	66	75	77	82
12	26.9	107	119	122	127	66	76	78	82
12	30.2	108	119	122	128	67	76	79	83
12	34.7	109	120	123	129	68	77	80	84
12	40.4	110	122	125	131	69	79	81	86
12	46.7	112	123	127	133	70	80	83	87
12	51.3	113	125	128	134	71	81	83	88
13	28.3	107	119	122	128	67	77	79	83
13	30.2	108	119	122	128	68	77	80	84
13	33.9	108	120	123	129	68	78	80	85
13	38.8	109	121	124	130	69	79	82	86
13	45	111	122	125	131	70	80	83	87
13	52	112	124	127	133	71	82	84	89
13	57	114	125	129	135	72	82	85	90
14	31.5	108	119	122	128	69	78	81	85
14	33.6	108	119	122	128	69	79	81	85
14	37.5	109	120	123	129	70	79	82	86
14	42.8	110	121	124	130	71	81	83	88
14	49.5	111	123	126	132	72	82	84	89
14	57	113	125	128	134	73	83	86	90
14	62.4	114	126	130	136	74	84	86	91
15	34.6	108	119	122	128	70	79	82	86
15	36.8	108	119	123	128	70	80	82	87
15	40.9	109	120	123	129	71	81	83	88
15	46.5	110	121	125	131	72	82	84	89
15	53.5	112	123	126	132	73	83	86	90
15	61.4	114	125	129	135	74	84	87	92
15	67	115	127	130	137	75	85	88	92
16	37.5	108	119	122	128	71	80	83	87

16	39.7	108	120	123	129	72	81	83	88
16	43.9	109	121	124	130	72	82	84	89
16	49.7	111	122	125	131	73	83	86	90
16	56.8	112	124	127	133	75	84	87	92
16	64.9	114	126	130	136	76	86	88	93
16	70.6	116	128	131	138	76	86	89	94
17	40	108	119	123	128	72	82	84	88
17	42.2	109	120	123	129	73	82	85	89
17	46.5	110	121	124	130	74	83	86	90
17	52.3	111	123	126	132	75	84	87	91
17	59.5	113	125	128	134	76	86	88	93
17	67.5	115	127	131	137	77	87	90	94
17	73.2	117	129	133	139	78	88	90	95
18	42.4	109	120	123	129	73	83	85	89
18	44.6	109	121	124	129	74	83	86	90
18	48.9	110	122	125	131	75	84	87	91
18	54.6	112	124	127	133	76	86	88	93
18	61.7	114	126	129	135	77	87	90	94
18	69.5	117	129	132	138	79	88	91	96
18	75	119	131	134	141	79	89	92	97

Weight in kilograms for each age represents the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentile.

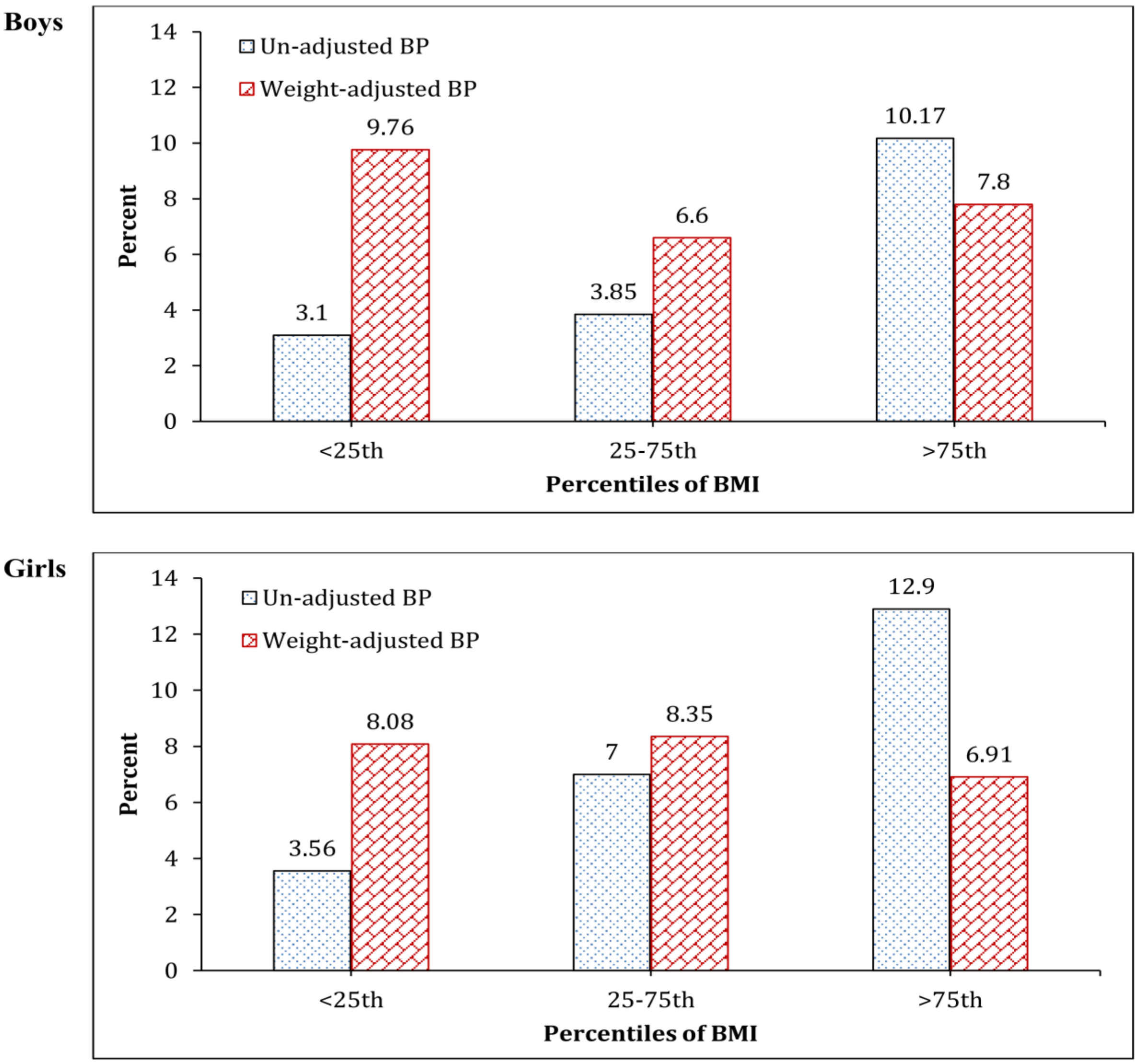

Fig.1: Prevalence of hypertension based on unadjusted blood pressure (BP) and weight-adjusted BP, for lean (<25th), average (25th-75th) and overweight and obese (>75th) children and adolescent base on body mass index (BMI) categories.

4- DISCUSSION

Considering its high prevalence and its various complications that lead to high morbidity and mortality rates, hypertension is regarded as a major public health issue worldwide (29). Since hypertension in adults is correlated with childhood BP levels, many studies have focused on developing normal standard references of BP for children and adolescents according to their age, gender, and anthropometric indices (14, 16, 35). For example the American Academy of Pediatrics Task Force on Blood Pressure developed standard references of BP levels according to age and height from birth to 18 years (13, 14, 36). In another study Neuhauser et al. (37) performed advanced statistical analyses on the data collected in the German Health Interview and Examination Survey for Children and Adolescents (KiGGS 2003-2006) (38) and developed standard BP references for non-overweight, children and adolescents of Germany aged 3 to 17 years old. The data presented in this study is the first BP reference developed by age and weight for Iranian children and adolescents. In previous surveys conducted in other countries the standard curves of BP were only drawn by age and gender. For example Tumer et al. included 5,599 Turkish infants and children under 18 years old (10) and developed normal BP curves based on the gathered information. Jackson et al. (8) derived BP centiles according to the data collected from 22,901 children aged 4 to 23 years old in Great Britain. In another survey conducted in Saudi Arabia, Al Salloum et al. (7) assessed 16,226 infants, children and adolescents under 18 years of age and developed BP reference percentiles. Mi et al. (16) also included data from eleven large-scale cross sectional surveys in China evaluating 112,227 children and adolescents aged 3 to 18 years old to construct BP references.

Furthermore, the prevalence of hypertension was calculated based on different references and among various groups of the study population considering the BMIs of boys and girls. The overall prevalence of hypertension based on US references (6.91% for girls and 5.67 for boys) was lower than the prevalence estimated based on Iranian weight-adjusted references (8.12% for girls and 8.38% for boys). Based on the standard curves of BP constructed according to weight, the prevalence of hypertension came up higher among the lean subjects and lower in the overweight and obese population, decreasing the chance of false judgments on the BP measurements.

To compare our results with the USA (13), Germany (17), Turkey (10), Great Britain (8), China (16), and Saudi Arabia (7) surveys, we derived the corresponding data on the ages of 3 to 18 years from these studies. For the information to be comparable, only data from the 50^{th} percentile of height from the German and American references and the 50^{th} percentile of weight from ours were included. The 95^{th} percentiles of BP by age for all the 7 mentioned surveys are depicted in **Figure.2**.

As illustrated, the SBP rose with age in a progressive manner among both genders, with the rise being steeper among boys after the age of 13. Slight differences were observed between DBP curves of both boys and girls.

The highest SBP levels are the Great Britain's and Saudi Arabia's. Minor differences can be observed between these two curves up to the age of 13, where their curves start to diverge and the Great Britain stays ahead. Up to the age of six, Iranian curve is the lowest for both genders. From that age on, although our BP levels are not the lowest of all but they are among the 2 or 3 lowest curves presented.

As for the DBP, the highest curve belongs to Saudi Arabia in almost all the ages for both genders, except among girls older than 15 years where Iranian curve exceeds theirs. Overall Iranian DBP curve presents with the steepest slope in a way that up to the age of 7, Iranian curve is among the two lowest curves but it increases to become the highest among girls and the second highest among boys after the age of 15. Great Britain's DBP curve presents with the mildest slope, downgrading among other curves till it becomes the lowest curve after the age of 9 years old.

One of the main strengths of our study is the large sample population which is nationally representative and covers a wide range of ages. Standardized measurements of BP and anthropometric indices, using a BP measuring device suitable for children, measuring BPs twice for each subject and the simultaneous modeling by age and weight with advanced statistical methods could be considered as other strengths of the present survey.

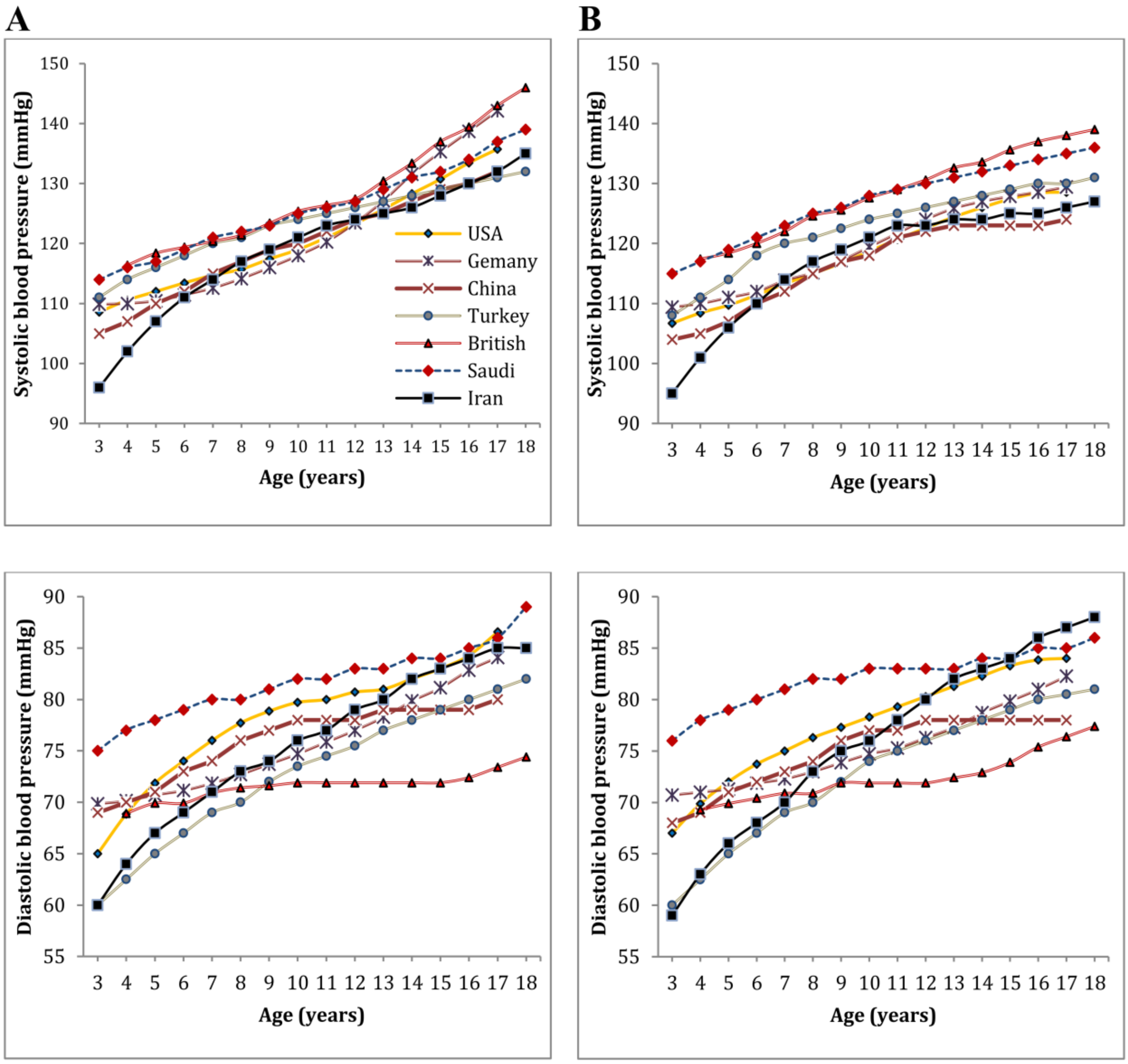

Fig.2: Comparison of the 95th percentile of blood pressure values in boys (A) and girls (B) from several countries. Blood pressure values of American (USA) and German children and adolescents correspond to the 50th percentile of height. Blood pressure values of Iranian children and adolescents correspond to the 50th percentile weight.

4-1. Limitations of the study

Since measurements were performed by human, our data were susceptible to end-digit preference, i.e. values ending in 0 or 5 were more frequently reported (39). The goodness of fit criteria were not entirely met and the fitted models changed with the prevalence of hypertension calculated based on these curves (40).

Another limitation of the present study is defining hypertension based on only 2 measurements, which can lead to slight inaccuracy in estimation of hypertension. A person cannot be introduced as hypertensive by 2 BP measurements with a short time interval. However in this study, hypertension prevalence was compared based on weight-adjusted BP and non-adjusted BP curves. So, the fact that the study's definition of hypertension might be inaccurate, does not affect the final findings and conclusion, as it has the same effect on the diagnostic accuracy of both standard curves.

5. CONCLUSION

The reference data developed in this study is the first Iranian BP reference by age and weight that covers children and adolescents aged 3 to 18 years old. BMI-adjusted BP curves were found to be a better tool for assessing the prevalence of hypertension in children and adolescents, on the basis of which a more reliable classification standard for hypertension could be obtained.

6- CONFLICT OF INTEREST: None.

7- ACKNOWLEDGMENTS

The authors would like to thank all the children, adolescents and their families for their cooperation. This research has been supported by Tehran University of Medical Sciences & health Services grant (Grant No 93-02-184-25774).

8- REFERENCES

1. Lawes CM, Hoorn SV, Rodgers A. Global burden of blood-pressure-related disease, 2001. The Lancet. 2008;371(9623):1513-8.

2. Somu S, Sundaram B, Kamalanathan A. Early detection of hypertension in general practice. Arch Dis Child. 2003;88(4):302-.

3. Raitakari OT, Juonala M, Kähönen M, Taittonen L, Laitinen T, Mäki-Torkko N, et al. Cardiovascular risk factors in childhood and carotid artery intima-media thickness in adulthood: the Cardiovascular Risk in Young Finns Study. JAMA. 2003;290(17):2277-83.

4. Bao W, Threefoot SA, Srinivasan SR, Berenson GS. Essential hypertension predicted by tracking of elevated blood pressure from childhood to adulthood: the Bogalusa Heart Study. Am J Hypertens. 1995;8(7):657-65.

5. Chen X, Wang Y. Tracking of blood pressure from childhood to adulthood a systematic review and meta–regression analysis. Circulation. 2008;117(25):3171-80.

6. Dekkers JC, Snieder H, van den Oord EJ, Treiber FA. Moderators of blood pressure development from childhood to adulthood: a 10-year longitudinal study. J Pediatr. 2002;141(6):770-9.

7. Al Salloum AA, El Mouzan MI, Al Herbish AS, Al Omar AA, Qurashi MM. Blood pressure standards for Saudi children and adolescents. Ann Saudi Med. 2009;29(3):173-8.

8. Jackson LV, Thalange NK, Cole TJ. Blood pressure centiles for Great Britain. Arch Dis Child. 2007;92(4):298-303.

9. Jafar TH, Islam M, Poulter N, Hatcher J, Schmid CH, Levey AS, et al. Children in South Asia Have Higher Body Mass–Adjusted Blood Pressure Levels Than White Children in the United States A Comparative Study. Circulation. 2005;111(10):1291-7.

10. Tümer N, Yalcinkaya F, Ince E, Ekim M, Köse K, Cakar N, et al. Blood pressure nomograms for children and adolescents in Turkey. Pediatr Nephrol. 1999;13(5):438-43.

11. Goonasekera C, Dillon M. Measurement and interpretation of blood pressure. Arch Dis Child. 2000;82(3):261-5.

12. Arafat M, Mattoo TK. Measurement of blood pressure in children: recommendations and perceptions on cuff selection. Pediatrics. 1999;104(3):e30.

13. Horan M. Report of the second Task Force on Blood Pressure Control in Children—1987. Pediatrics. 1987;79(1):1-25.

14. National High Blood Pressure Education Program. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. Pediatrics. 2005;114:255–76.

15. Gifford R, August P, Cunningham G, Green L, Lindheimer M, McNellis D, et al. Report of the national high blood pressure education program working group on high blood pressure in pregnancy. Am J Obstet Gynecol. 2000;183(1):S1-S22.

16. Mi J, Wang T-y, Meng L-h, Zhu G-j, Han S-m, Zhong Y, et al. Development of blood pressure reference standards for Chinese children. Chin J Evid Based Pediatr. 2010;5(1):4-14.

17. Neuhauser HK, Thamm M, Ellert U, Hense HW, Rosario AS. Blood pressure percentiles by age and height from nonoverweight children and adolescents in Germany. Pediatrics. 2011:e978-88.

18. Ashrafi M, Abdollahi M, Ahranjani B, Shabanian R. Blood pressure distribution among healthy schoolchildren aged 6-13 years in Tehran. East Mediterr Health J. 2005;11(5-6):968-76.

19. Ataei N, Aghamohammadi A, Yousefi E, Hosseini M, Nourijelyani K, Tayebi M, et al. Blood pressure nomograms for school children in Iran. Pediatr Nephrol. 2004;19(2):164-8.

20. Ayatollahi S, Vakili M, Behboodian J, Zare N. Reference Values for Blood Pressure of Healthy Schoolchildren in Shiraz (Southern Iran) using Quantile Regression. Iran Cardiovasc Res J. 2010;4(2):55-65.

21. Kelishadi R, Ardalan G, Gheiratmand R, Majdzadeh R, Delavari A, Heshmat R, et al. Blood pressure and its influencing factors in a national representative sample of Iranian children and adolescents: the CASPIAN Study. Eur J Cardiovasc Prev Rehabil. 2006;13(6):956-63.

22. Ataei N, Hosseini M, Fayaz M, Navidi I, Taghiloo A, Kalantari K, et al. Blood pressure percentiles by age and height for children and adolescents in Tehran, Iran. J Hum Hypertens. 2016;30(4):268-77.

23. Hu G, Barengo NC, Tuomilehto J, Lakka TA, Nissinen A, Jousilahti P. Relationship of physical activity and body mass index to the risk of hypertension: a prospective study in Finland. Hypertension. 2004;43(1):25-30.

24. Brown CD, Higgins M, Donato KA, Rohde FC, Garrison R, Obarzanek E, et al. Body mass index and the prevalence of hypertension and dyslipidemia. Obes Res. 2000;8(9):605-19.

25. Stamler R, Stamler J, Riedlinger WF, Algera G, Roberts RH. Weight and blood pressure: findings in hypertension screening of 1 million Americans. JAMA. 1978;240(15):1607-10.

26. Hosseini M, Carpenter R, Mohammad K. Growth charts for Iran. Ann Hum Biol. 1998;25(3):237-47.

27. Hosseini M, Baikpour M, Yousefifard M, Mansournia MA, Yaseri M, Asady H, et al. Body Mass Index Percentile Curves for 7 To 18 Year Old Children and Adolescents; are the Sample Populations from Tehran Nationally Representative? Int J Pediatr. 2016;4(6):1926-34.

28. Hosseini M, Navidi I, Hesamifard B, Yousefifard M, Jafari N, Ranji Poorchaloo S, et al. Weight, Height and Body Mass Index Nomograms; Early Adiposity Rebound in a Sample of Children in Tehran, Iran. Int J Prev Med. 2013;4(12):1414-20.

29. Ataei N, Aghamohammadi A, Ziaee V, Hosseini M, Dehsara F, Rezanejad A. Prevalence of hypertension in junior and senior high school children in Iran. Iran J Pediatr. 2007;17(Suppl 2):237-42.

30. Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. Stat Med. 1992;11(10):1305-19.

31. Stanojevic S, Wade A, Stocks J, Hankinson J, Coates AL, Pan H, et al. Reference ranges for spirometry across all ages: a new approach. Am J Respir Crit Care Med. 2008;177(3):253.

32. Cole T, Stanojevic S, Stocks J, Coates A, Hankinson J, Wade A. Age-and size-related reference ranges: A case study of spirometry through childhood and adulthood. Stat Med. 2009;28(5):880-98.

33. Rigby R, Stasinopoulos D. Generalized additive models for location, scale and shape. J R Stat Soc Ser C Appl Stat. 2005;54(3):507-54.

34. Falkner B, Daniels SR. Summary of the Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents. Hypertension. 2004;44(4):387-8.

35. Muntner P, He J, Cutler JA, Wildman RP, Whelton PK. Trends in blood pressure among children and adolescents. JAMA. 2004;291(17):2107-13.

36. National Heart Lung Blood Institute. Update on the 1987 Task Force Report on High Blood Pressure in Children and Adlescents: A Work Group Report from the National High Blood Pressure Education Program. Pediatrics. 1996;98:649-57.

37. Neuhauser HK, Thamm M, Ellert U, Hense HW, Rosario AS. Blood pressure percentiles by age and height from nonoverweight children and adolescents in Germany. Pediatrics. 2011;127(4):e978-e88.

38. Kamtsiuris P, Lange M, Schaffrath RA. The German Health Interview and Examination Survey for Children and Adolescents (KiGGS): sample design, response and nonresponse analysis. Bundesgesundheitsblatt, Gesundheitsforschung, Gesundheitsschutz. 2006;50(5-6):547-56.

39. Alsanjari O, de Lusignan S, van Vlymen J, Gallagher H, Millett C, Harris K, et al. Trends and transient change in end-digit preference in blood pressure recording: studies of sequential and longitudinal collected primary care data. Int J Clin Pract. 2012;66(1):37-43.

40. Wen SW, Kramer MS, Hoey J, Hanley JA, Usher RH. Terminal digit preference, random error, and bias in routine clinical measurement of blood pressure. J Clin Epidemiol. 1993;46(10):1187-93.