IJKD KIDNEY DISEASES

Simple Memorable Formulas for Screening Hypertension in Children: Based on the New American Academy of Pediatrics Guideline

Afagh Hassanzadeh Rad,[1] Jahangir Kamalpour,[2] Behrad Badeli,[3] Daniel Badeli,[4] Hamidreza Badeli[1]

[1]Pediatric Diseases Research Center, Guilan University of Medical Sciences, Rasht, Iran
[2]School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran
[3]Mathematics and Physics Student, Sampad Mirzakoochakkhan Highschool, Rasht, Iran
[4]BSc Biomedical Sciences, University of Southampton, MBBS4 Student at St George's University of London, UK

Keywords. blood pressure, child, hypertension

Original Paper

Introduction. Hypertension (HTN), also known as high blood pressure (BP), is a major global risk factor for cardiovascular and kidney diseases. Although annual BP screenings for children over three years of age are recommended, underdiagnosis of HTN in children is common. To address this issue, the American Academy of Pediatrics updated its guideline for screening and managing high BP in children in 2017, which can be cumbersome to implement in clinical practice due to the numerous cut-off points and tables. The purpose of our study is to design formulas to detect HTN in children based on the new Clinical Practice Guideline for screening and management of high BP in children and adolescents.
Methods. In this research, we analyzed forty-eight cut-off points using the 90th percentile systolic and diastolic BPs for the fifth percentile height. The final mathematical model consisted of four formulas based on different ages and sex which in turn were rounded by 0.1 and 1.0 for both systolic and diastolic BPs. The formulas were further modified to be lower than the 95th percentile systolic BPs for the fifth percentile of height to minimize false negative results.
Results. As evidenced by the tables included in this paper, except for a few exceptions, all rounded systolic and diastolic values for both sexes were equal to or lower than the 90th percentile. In a few cases where the cutoff points calculated by the formula were higher than the ones provided in the 2017 guideline, the differences were less than 2 mmHg.
Conclusion. In this study to address the complexity of the routine guidelines, we present simplified formulas for screening children aged 1 to 12 years in figures and tables and recommend their use, particularly in office and emergency settings, as an easier-to-implement first step in screening for HTN in children.

IJKD 2023;17:306-13
www.ijkd.org
DOI: 10.52547/ijkd.7525

INTRODUCTION

Hypertension (HTN), also known as high blood pressure (BP), is a major global risk factor for cardiovascular and kidney diseases.[1,2] It accounts for 8.5 million deaths due to stroke, ischemic heart disease, and vascular and renal diseases.[3,4] Previous research have suggested that childhood hypertension is associated with essential hypertension and cardiovascular diseases in adulthood.[5,6,7] Over the past decade, there has

been a considerable increase in the average BP in children, owing primarily to the increasing prevalence of childhood obesity as overindulgence in food has become a more significant issue in many nations, compared to diseases related to starvation.[8,9] The prevalence of hypertension in children is estimated to be between 2 to 4%.[10] As hypertension has been linked to increased morbidity and mortality,[11] early identification of children with elevated BP is a crucial strategy for reducing the risk of cardiovascular diseases and death.[12]

Hypertension in children is defined as a systolic BP (SBP) or diastolic BP (DBP) ≥90-95th percentile for sex, age, and height. [13] Although annual screening of childhood blood pressure over three years is recommended, HTN is frequently underdiagnosed in children.[14] In 2017, the American Academy of Pediatrics (AAP) updated its guideline for screening and managing childhood high BP (the AAP guideline). [1]

Like the US Fourth Report,[15] the AAP guideline is cumbersome in clinical practice and contains numerous BP cut-off points according to sex, age, and height.[1] This may be one of the main reasons why pediatric HTN is commonly underdiagnosed even when BP measurements are accessible.[16]

To address the complexity of routine screening of hypertension in children, the American Academy of Pediatrics (AAP) endorsed the use of the simplified BP table developed by Kaelber *et al.*, which is based only on sex and age at the fifth percentile height for children aged 1 to 12 years.[17] The simplified BP table has 48 BP cut-off points for identifying elevated BP in children, compared to 336 cut-off points in the American Academy of Pediatrics (AAP) guidelines. The AAP expects the sensitivity of the simplified table to be extremely accurate for screening BP because height has a significant role in predicting BP in children and the cut-off points are based on BP at a low height percentile (i.e. P5).[17]

Despite the applicability of the recent valuable table summarizing the American Academy of Pediatrics (AAP) guideline for hypertension in children, practitioners still need to refer to the table when measuring BP. Previous investigators have attempted to address this issue by designing simplified formulas for detecting HTN in children. Badeli *et al.* (2010),[18] recommended six formulas based on age and sex in accordance with the 2004 guideline. In this study, we further sought to simplify the process by designing only two formulas for detecting HTN in children based on the 2017 American Academy of Pediatrics (AAP) guidelines.[19]

MATERIALS AND METHODS

In this study, we designed simple formulas based on the latest American Academy of Pediatrics (AAP) guideline (2017) that are applicable irrespective of height and sex. First, the forty-eight cut-off points were analyzed based on the 90th systolic and diastolic BPs for the fifth percentile of height. The mean of the cut points for both sexes was calculated to provide twenty-four cut points and design a model regardless of sex.

The first mathematical model consisted of four formulas based on different ages and sex. We rounded all of our designed formulas by 0.1 and 1 for both systolic and diastolic BPs and made minor adjustments to account for rounding errors and prevent underdiagnoses. We applied the same procedures to the averaged cut-off points and generated two formulas.

To further enhance the accuracy of our formulas, we attempted to design them to be lower than the 95th percentile systolic BPs for the fifth percentile of height to avoid false negative results. It is notable that since the formula provides values that are acceptable according to the original cut-off points which can be observed straightforwardly, no statistical analysis was needed. In addition, we provided figures and tables to present simplified formulas for screening children aged 1 to 12 years. It is important to note that BP cutoffs for children aged over 13 years are the same as those for adults (> 120 SBP and > 80 DBP).[20] ETHICAL CONSIDERATION This study was approved by the ethics committee of Guilan University of Medical Sciences (Number: 3/132/2154).

RESULTS

In this study, we provided simplified formulas for screening blood pressure in children aged 1 to 12 years. Tables 1 and 2, respectively; show the systolic and diastolic outputs and rounded results in boys and girls, compared to the 90th and 95th percentile systolic BPs for the fifth percentile of height. As Table 1 and Figures 1 and 2 indicate, all rounded systolic and diastolic values for boys

Table 1. The Calculated Systolic and Diastolic BPs in Boys

Age	Systolic (mmHg)[a]	Systolic RO (mmHg)[b]	Rounded Systolic RO (mmHg)	SBP 95th (mmHg)[c]	Diastolic (mmHg)[d]	Diastolic RO (mmHg)	Rounded Diastolic RO (mmHg)	DBP 95th (mmHg)
1	98	98.6	99	102	52	54.5	54	54
2	100	99.8	100	104	55	56.4	56	57
3	101	101.0	101	106	58	58.3	58	60
4	102	102.2	102	107	60	60.2	60	63
5	103	103.4	103	107	63	62.1	62	66
6	105	104.6	104	108	66	64.0	64	69
7	106	105.8	105	110	68	65.9	66	71
8	107	107.0	106	111	69	67.8	68	72
9	107	108.2	107	112	70	69.7	70	74
10	108	109.4	108	112	72	71.6	72	76
11	110	110.6	109	114	74	73.5	74	77
12	113	111.8	110	116	75	75.4	76	78

note: a, 90th systolic BP for the 5th percentile of height; b, formula Output; c,**95th systolic BP for 5th percentile of height; d, 90th diastolic BP for the 5th percentile of height

Table 2. The Calculated Systolic and Diastolic BPs in Girls

Age	Systolic (mmHg)[a]	Systolic RO (mmHg)[b]	Rounded Systolic RO (mmHg)	SBP 95th (mmHg)[c]	Diastolic (mmHg)[d]	Diastolic RO (mmHg)	Rounded Diastolic RO (mmHg)	DBP 95th (mmHg)
1	98	99.4	100	101	54	57.1	55	59
2	101	100.6	101	104	58	58.8	57	62
3	102	101.8	102	106	60	60.5	59	64
4	103	103.0	103	107	62	62.2	61	66
5	104	104.2	104	108	64	63.9	63	68
6	105	105.4	105	109	67	65.6	65	70
7	106	106.6	106	109	68	67.3	67	72
8	107	107.8	107	110	69	69.0	69	72
9	108	109.0	108	112	71	70.7	71	74
10	109	110.2	109	113	72	72.4	73	75
11	111	111.4	110	115	74	74.1	75	76
12	114	112.6	111	118	75	75.8	77	78

note: a, 90th systolic BP for the 5th percentile of height; b, formula Output; c,**95th systolic BP for 5th percentile of height; d, 90th diastolic BP for the 5th percentile of height

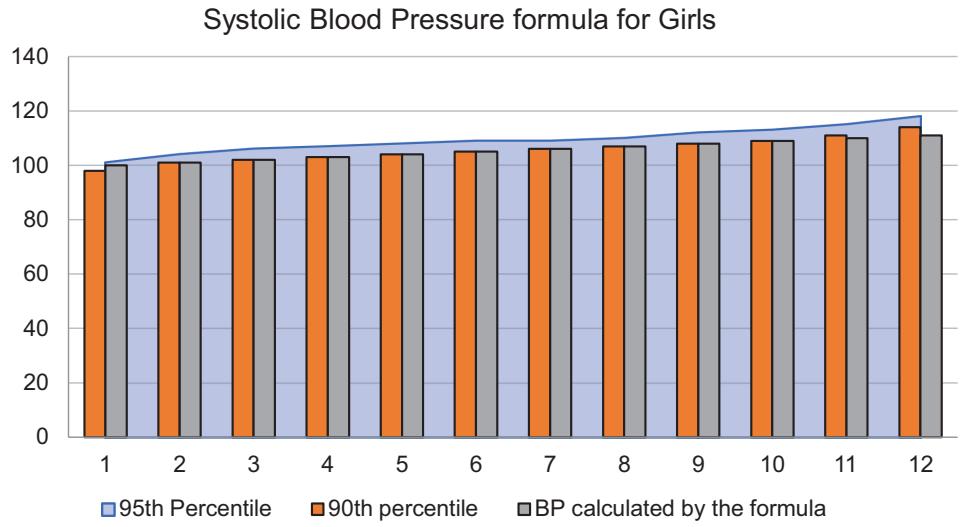

Figure 1. Comparing Systolic BPs in Girls and Their Counterparts Calculated by the Formula

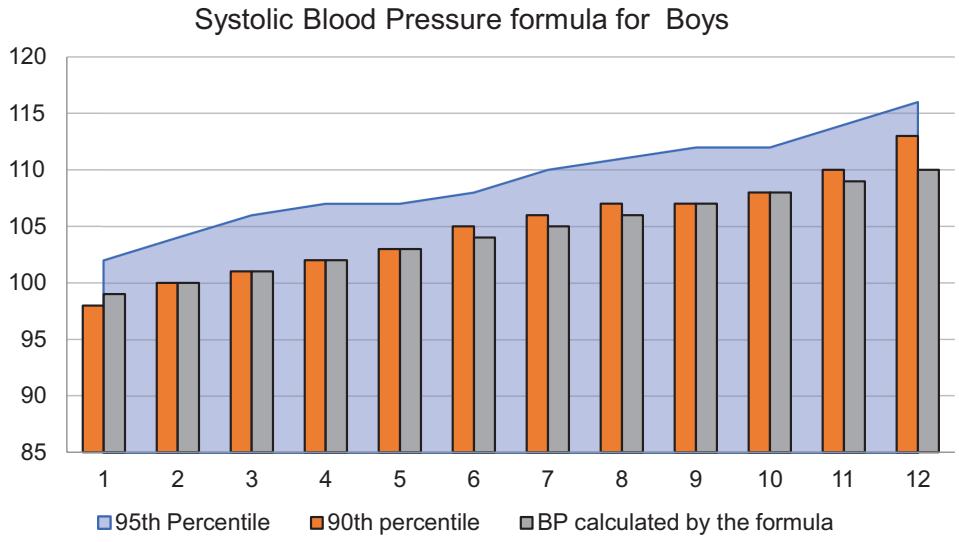

Figure 2. Comparing Systolic BPs in Boys and Their Counterparts Calculated by the Formula

were equal to or lower than the 90th percentile except for those at age one (≤ 2 mmHg higher than systolic and diastolic BPs, respectively) and age two and twelve (≤ 1 mmHg for diastolic BPs). Besides, Table 2 and Figures 3 and 4 in girls show that only systolic BP at age one was 2 mmHg more than the 90th systolic BPs for the fifth percentile of height. However, rounded values of diastolic BPs for ages one and 10 to 12 years were ≤ 1 to 2 mmHg greater than the 90th diastolic BPs for the 5th percentile of height. Notably, all forty-eight systolic and diastolic BPs rounded results were lower than the 95th BPs for the fifth percentile of height except at age one in boys, which was equal to the 95th percentile of diastolic value (Figures 1 to 4).

To provide a simplified and easily understandable representation of results, we used Table 3 to display our model for systolic and diastolic BPs regardless of sex. This table allows for the straightforward interpretation of the findings and their potential clinical usefulness. It shows that all twenty-four systolic and diastolic rounded results were lower than the 95th BPs for the fifth percentile of height except for age one in boys, which was equal to the diastolic value (Figure 5 to 6).

According to the new American Academy of Pediatrics (AAP) guideline (2017), BP ≤ 120/80 mmHg is considered normal for children over 13

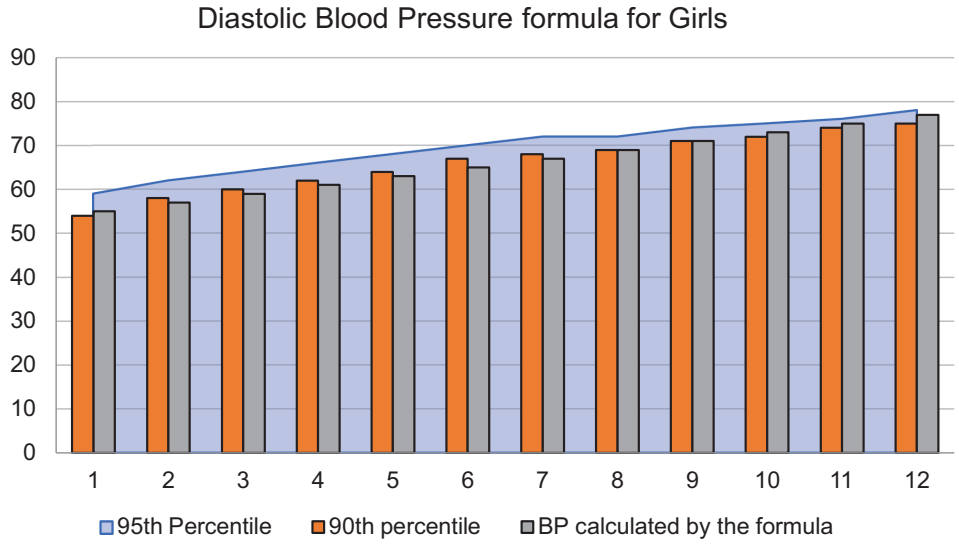

Figure 3. Comparing Diastolic BPs in Girls and Their Counterparts Calculated by the Formula

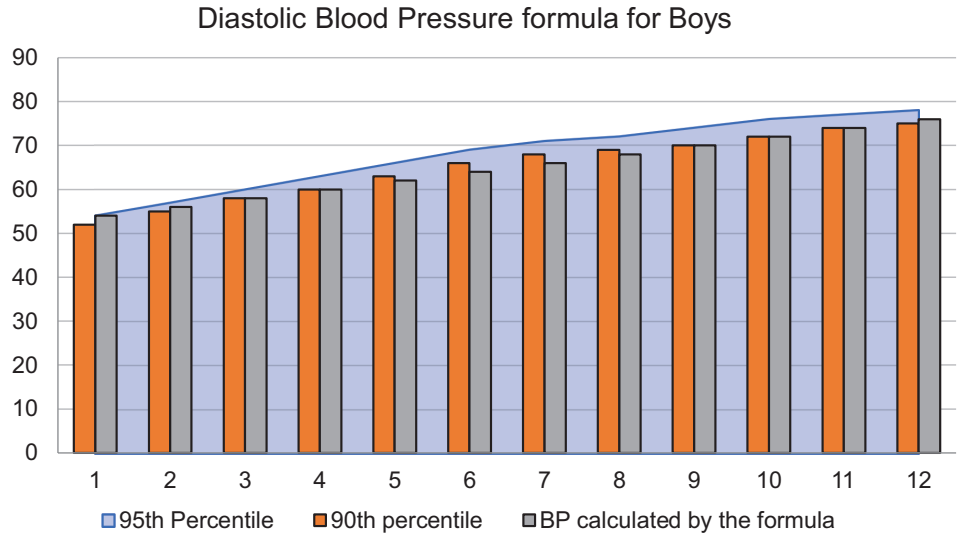

Figure 4. Comparing Diastolic BPs in Boys and Their Counterparts Calculated by the Formula

years old, irrespective of sex.

We compared calculated systolic and diastolic BPs and 90th BP percentile across genders in Figures 1 to 4. We also added the 95th percentile of blood pressure in the fifth percentile of height. These figures show that no calculated value is above the 95th percentile in the fifth percentile of height which shows that there will not be any under-diagnosis.

Table 4 shows the detailed formula and rounded output regarding sex in rows one and two. Row three of this table shows the final formula for estimating normal systolic and diastolic blood pressures in children aged 1 to 12, regardless of sex. As seen in the table, the formula for systolic blood pressure is AGE+98, while the formula for diastolic blood pressure is AGE×2+52. (Figures 5 to 6).

DISCUSSION

Hypertension (HTN) in children and adolescents is a growing concern, as it can cause significant morbidity and mortality if not effectively managed. It is essential to diagnose and treat HTN in this demographic to prevent the development of long-term health complications. Early detection and treatment of HTN in children and adolescents can help to reduce the risk of future cardiovascular and kidney diseases and improve overall health outcomes.

The diagnosis of HTN in individuals over 13 years of age is relatively straightforward due to a clear cut-off value.[20] However, the diagnosis of HTN in children younger than 13 years old is more complex due to the various cut-off points provided in tables based on variables such as sex, age, and height. In many clinical settings, including busy medical clinics and emergencies where time is limited, accessing and interpreting tables can be challenging. As a result, there is a need for less complicated and more readily applicable methods for diagnosing HTN in children under 13 years of age.

Therefore, we proposed two simple and memorable formulas for easier use of the recent guideline of AAP 2017.[1] The Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents is a guideline with 476 values based on sex, age, and height percentiles.[15] In comparison to The Fourth Report, Kaelber *et al.* created a less complex, simplified table of 64 values for identifying children and adolescents needing further evaluation of blood pressure.[17] They only focused on constructing their table based on a single threshold of abnormal BP levels, categorized by sex and age, for children from 3 -18 years old. They claimed that their table could quickly and easily detect children needing further evaluation and rule out abnormal BPs.[19]

Previous investigations tried to provide simplified methods for screening elevated or high blood pressure in children.[12] To the best of our knowledge, most of these investigations provided only rudimentary tables[21] and some established formulas. As most of these methods were height-based[12], clinicians have to consider

Table 3. The Calculated Systolic and Diastolic BPs in Total Across Both Genders

Age	Girls Systolic (mmHg)[a]	Girls Systolica (mmHg)	Systolic RO (mmHg)[b]	Rounded Systolic RO (mmHg)	Boys SBP 95th c (mmHg)	Girls SBP 95th (mmHg)[c]	Boys Diastolic (mmHg)[d]	Girls Diastolicd (mmHg)	Diastolic RO (mmHg)	Rounded Diastolic RO (mmHg)	Boys DBP 95th (mmHg)	Girls DBP 95th (mmHg)
1	98.0	98.0	99.0	99	102	101	52	54.0	55.8	54	54	59
2	100.0	101.0	100.2	100	104	104	55	58.0	57.6	56	57	62
3	101.0	102.0	101.4	101	106	106	58	60.0	59.4	58	60	64
4	102.0	103.0	102.6	102	107	107	60	62.0	61.2	60	63	66
5	103.0	104.0	103.8	103	107	108	63	64.0	63.0	62	66	68
6	105.0	105.0	105.0	104	108	109	66	67.0	64.8	64	69	70
7	106.0	106.0	106.2	105	110	109	68	68.0	66.6	66	71	72
8	107.0	107.0	107.4	106	111	110	69	69.0	68.4	68	72	72
9	107.0	108.0	108.6	107	112	112	70	71.0	70.2	70	74	74
10	108.0	109.0	109.8	108	112	113	72	72.0	72.0	72	76	75
11	110.0	111.0	111.0	109	114	115	74	74.0	73.8	74	77	76
12	113.0	114.0	112.2	110	116	118	75	75.0	75.6	76	78	78

multiple variables, which can be time-consuming.

Previous study by Badeli, Sajedi, and Shakiba (2010) presented four concise and memorable formulas to screen prehypertensive and hypertensive pediatric patients irrespective of height using the tables presented in the Fourth Report (2004).[15]

In an earlier investigation, Ma *et al*. analyzed the effectiveness of eleven simplified methods in their study to find children and adolescents with high blood pressure. They assessed the methods and found that they performed well in screening high BP.[12] Notably, Flynn *et al*. designed a comprehensive and accurate calculator for detecting normal, elevated, stage 1, and stage 2 HTN in children. Although it exempted clinicians from using multiple tables, it still needs height measurement and access to its URL address which requires a stable internet access and appropriate permissions.[19]

STRENGHTS AND LIMITATIONS

In this study, we developed four detailed (with decimals) formulas for screening systolic and diastolic BPs based on sex and age. However, to make these formulas more understandable and applicable in clinical practice, we rounded those four sex- and age-based formulas and omitted the decimals. Finally, we introduced two accurate, simple, and memorable formulas irrespective of sex and height for detecting standard blood pressure cutoffs.

As our results were lower than the 95th percentile of blood pressure in the fifth percentile of height, this formula can be applied for screening HTN in children. Even though our final formulas [systolic B*P* = Age + 98 and diastolic B*P* = (AGE × 2) + 52] were based on healthy children, we cannot neglect the importance of having up-to-date comprehensive tables, formulas, and calculators for susceptible individuals and special groups which entails further research and analysis in the future.

CONCLUSION

In conclusion, we developed simplified formulas that can be applied to address the complexity of the routine guidelines for the diagnosis of HTN in children under 13 years of age. These formulas are particularly helpful to use in office and emergency settings as a quick and easy first step in the HTN screening process. We recommend using these formulas to facilitate the early detection and

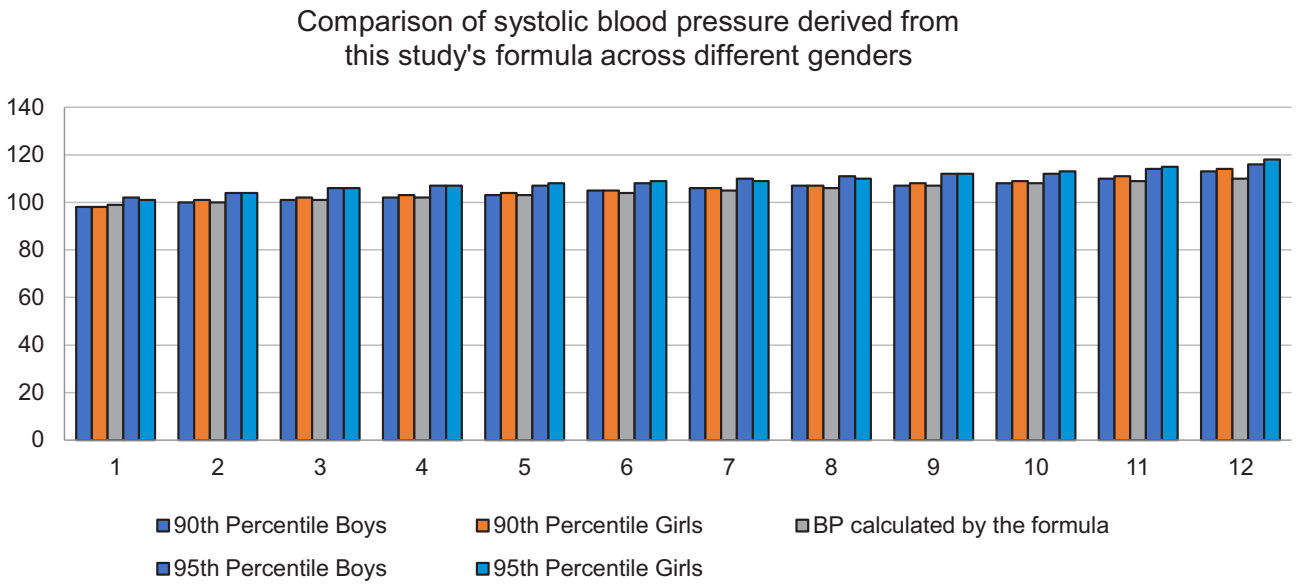

Figure 5. Comparing Calculated Systolic BPs and Gender Specific Data

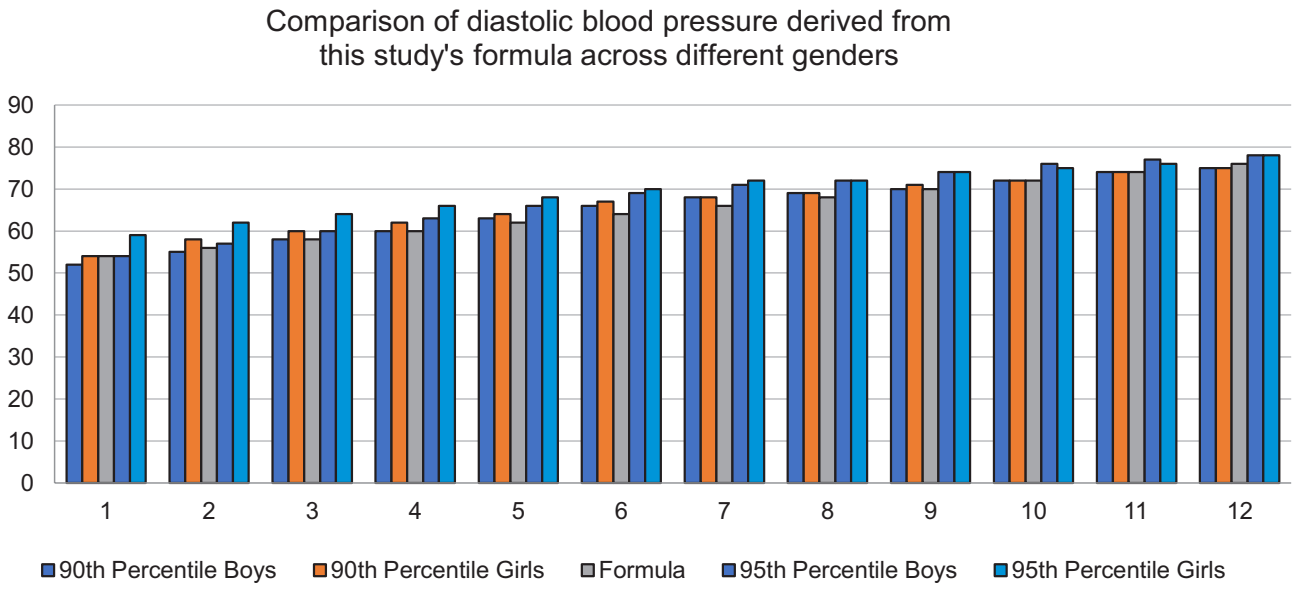

Figure 6. Comparing Calculated Diastolic BPs and Gender Specific Data

Table 4. The Final Formula for Boys and Girls and the Total Population

Variables	BPs			
	SBP		DBP	
	Detailed Formula	Rounded Formula	Detailed Formula	Rounded Formula
Boys	(AGE×1.2)+97.4	AGE+98	(AGE×1.9)+52.6	(AGE×2)+52
Girls	(AGE×1.2)+98.2	AGE+99	(AGE×1.7)+55.4	(AGE×2)+53
Total Population	(AGE×1.2)+97.8	AGE+98	(AGE×1.8)+54.0	(AGE×2)+52

management of HTN in children and adolescents, which can help to reduce the risk of long-term health complications and improve overall health outcomes.

REFERENCES

1. Flynn JT, Kaelber DC, Baker-Smith CM, Blowey D, Carroll AE, Daniels SR, et al. Clinical Practice Guideline for Screening and Management of High Blood Pressure in

Children and Adolescents. Pediatrics. 2017;140(3).

2. Zhou B, Bentham J, Di Cesare M, et al; NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in blood pressure from 1975 to 2015: a pooled analysis of 1479 population-based measurement studies with 19·1 million participants. Lancet. 2017;389(10064):37-55.
3. Olsen MH, Angell SY, Asma S, Boutouyrie P, Burger D, Chirinos JA, Damasceno A, Delles C, Gimenez-Roqueplo AP, Hering D, Lopez-Jaramillo P. A call to action and a lifecourse strategy to address the global burden of raised blood pressure on current and future generations: the Lancet Commission on hypertension. The Lancet. 2016 Nov 26;388(10060):2665-712.
4. Zhou B, Perel P, Mensah GA, Ezzati M. Global epidemiology, health burden and effective interventions for elevated blood pressure and hypertension. Nature Reviews Cardiology. 2021 Nov;18(11):785-802.
5. 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):657-665. doi:10.1016/0895-7061(95)00116-7PubMedGoogle ScholarCrossref
6. Raitakari OT, Juonala M, Kähönen M, 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):2277-2283. doi:10.1001/jama.290.17.2277
7. Beckett LA, Rosner B, Roche AF, Guo S. Serial changes in blood pressure from adolescence into adulthood. Am J Epidemiol. 1992;135(10):1166-1177. doi:10.1093/oxfordjournals.aje.a116217PubMedGoogle ScholarCrossref
8. Din-Dzietham R, Liu Y, Bielo M-V, Shamsa F. High blood pressure trends in children and adolescents in national surveys, 1963 to 2002. Circulation. 2007;116(13):1488-1496.
9. Muntner P, He J, Cutler JA, Wildman RP, Whelton PK. Trends in blood pressure among children and adolescents. JAMA. 2004;291(17):2107-2113. doi:10.1001/jama.291.17.2107
10. Din-Dzietham R, Liu Y, Bielo M-V, Shamsa F. High blood pressure trends in children and adolescents in national surveys, 1963 to 2002. Circulation. 2007;116(13):1488-1496.
11. Hardy ST, Urbina EM. Blood Pressure in Childhood and Adolescence. Am J Hypertens. 2021;34(3):242-9.
12. Ma C, Kelishadi R, Hong YM, Bovet P, Khadilkar A, Nawarycz T, Krzywińska-Wiewiorowska M, Aounallah-Skhiri H, Zong XN, Motlagh ME, Kim HS. Performance of eleven simplified methods for the identification of elevated blood pressure in children and adolescents. Hypertension. 2016 Sep;68(3):614-20.
13. Thomas J, Stonebrook E, Kallash M. Pediatric hypertension: Review of the definition, diagnosis, and initial management. International Journal of Pediatrics and Adolescent Medicine. 2020 Oct 15.
14. Hansen ML, Gunn PW, Kaelber DC. Underdiagnosis of hypertension in children and adolescents. JAMA. 2007;298:874–879. doi: 10.1001/Jama.298.8.874.
15. National High Blood Pressure Education Program Working Group on High Blood Pressure in C, Adolescents. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. Pediatrics. 2004; 114:555–576.
16. Moin A, Mohanty N, Tedla YG, Carroll AJ, Padilla R, Langman CB, Smith JD. Under-recognition of pediatric hypertension diagnosis: Examination of 1 year of visits to community health centers. The Journal of Clinical Hypertension. 2021 Feb;23(2):257-64.
17. Kaelber DC, Pickett F. Simple table to identify children and adolescents needing further evaluation of blood pressure. Pediatrics. 2009 Jun;123(6):e972-4.
18. Badeli H, Sajedi SA, Shakiba M. Simple formulas for screening abnormal blood pressure in children and adolescents. Iran J Kidney Dis. 2010 Jul;4(3):250-2.
19. Flynn JT, Kaelber DC, Baker-Smith CM. The simplified table in the 2017 American Academy of Pediatrics childhood hypertension guideline performs exactly as intended. J Hypertens. 2018 Dec;36(12):2479-2480.
20. Riley M, Hernandez AK, Kuznia AL. High Blood Pressure in Children and Adolescents. Am Fam Physician. 2018;98(8):486-94.
21. Mitchell CK, Theriot JA, Sayat JG, Muchant DG, Franco SM. A simplified table improves the recognition of paediatric hypertension. J Paediatr Child Health. 2011;47(1-2):22-6

Correspondence to:
Hamidreza Badeli, MD
Pediatric Diseases Research Center, Guilan University of Medical Sciences, Rasht, Iran
E-mail: badeli@gums.ac.ir
Tel : 0098 911 239 7157

Received June 2023
Revised August 2023
Accepted October 2023