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ARTICLE

Height-specific blood pressure cutoffs for screening elevated and high blood pressure in children and adolescents: an International Study

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Abstract

Pediatric blood pressure (BP) reference tables are generally based on sex, age, and height and tend to be cumbersome to use in routine clinical practice. In this study, we aimed to develop a new, height-specific simple BP table according to the international child BP reference table based on sex, age and height and to evaluate its performance using international data. We validated the simple table in a derivation cohort that included 58,899 children and adolescents aged 6–17 years from surveys in 7 countries (China, India, Iran, Korea, Poland, Tunisia, and the United States) and in a validation cohort that included 70,072 participants from three other surveys (China, Poland and Seychelles). The BP cutoff values for the simple table were calculated for eight height categories for both the 90th ("elevated BP") and 95th ("high BP") percentiles of BP. The simple table had a high performance to predict high BP compared to the reference table, with high values (boys/girls) of area under the curve (0.94/0.91), sensitivity (88.5%/82.9%), specificity (99.3%/99.7%), positive predictive values (93.9%/97.3%), and negative predictive values (98.5%/97.8%) in the pooled data from 10 studies. The simple table performed similarly well for predicting elevated BP. A simple table based on height only predicts elevated BP and high BP in children and adolescents nearly as well as the international table based on sex, age, and height. This has important implications for simplifying the detection of pediatric high BP in clinical practice.

Keywords adolescents · children · epidemiology · high blood pressure · elevated blood pressure · methodology

Introduction

High blood pressure (BP) in children and adolescents is usually identified according to BP cutoff values tabulated based on sex, age, and height percentiles [1–3], which is cumbersome to use in routine clinical practice because of the large number of BP cutoffs. In 2016, we developed an international BP reference table for children and adolescents aged 6–17 years tabulated based on sex, age, and height percentiles [3], consistent with other standard guidelines to detect elevated BP and high BP in children and adolescents [1, 2]. This international BP reference table, which was developed using data from 7 countries on 4 continents, is useful for a global comparison of the prevalence of high BP in children and adolescents, as well as to identify high BP in

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different populations. However, this international reference table, similar to other child BP guidelines by sex, age, and height [1, 2], includes more than 300 cutoff points to predict elevated BP and high BP.

Several studies have shown that high BP is often not identified in children and adolescents in clinical practice, even when BP was measured [4, 5]. The underdiagnosis of pediatric hypertension may be due to a lack of awareness of this problem in children but also to the complexity of the reference tables [4, 5] that rely on several hundreds of BP cutoffs based on sex, age, and height strata, making such tables cumbersome to use in clinical practice. Thus, it would be useful if high BP in youths could be assessed using a simpler tool with a lower number of BP cutoff values. Several simpler tools have been developed to screen high BP in children and adolescents, including tables displaying BP cutoffs by sex and age only, simple mathematical formulas, a BP to height ratio, and a table displaying BP cutoffs based on height only [6, 7]. We previously showed that a table displaying BP cutoffs based on height only performed best among eleven simple tools to assess high BP in youths, compared to the most widely used U.S. Fourth Report table based on sex, age, and height [7].

In this paper, we developed a simple table based on height only using the international BP table as the reference, and we further evaluated its performance both internally and externally using data from eight countries.

Methods

Development of absolute height-specific BP cutoffs

We developed a simple table of BP cutoffs for "elevated BP" (90th BP percentile) and "high BP" (95th BP percentile) for eight height categories with 10 cm increments, i.e., < 115, 115–124, 125–134, 135–144, 145–154, 155–164, 165–174, and ≥175 cm, respectively, for children and adolescents aged 6–17 years. We chose height categories according to the paper by Chiolero et al. [8] that first evaluated this approach. It should be noted that the choice of height categories should not necessarily be based on a particular study population, since height distribution may vary between populations. In this manuscript, we refer to this table as the "simple table" (Table 1). Our comparison reference table was the international table based on sex, age, and height [3]. For each sex, if a height percentile in the international BP table fell into any of the eight height categories, the corresponding systolic BP (SBP) and diastolic BP (DBP) values were averaged to define the BP cutoffs. The process followed the methods used by Chiolero et al. [8]. As there were no substantial sex differences in BP cutoffs for a given height category, we averaged the values for boys and girls (i.e., the same absolute height-specific BP cutoff would apply for both boys and girls).

Table 1 Blood pressure cutoffs based on height only in children and adolescents aged 6–17 years

Height range, cm	90th percentile		95th percentile	
	SBP, mm Hg	DBP, mm Hg	SBP, mm Hg	DBP, mm Hg
<115	106	72	109	76
115–124	107	73	111	77
125–134	110	74	114	78
135–144	113	76	117	79
145–154	118	77	121	81
155–164	120	79	125	83
165–174	120	80	129	84
≥175	120	80	134	86

SBP systolic blood pressure, *DBP* diastolic blood pressure

Derivation data

The derivation data included 58,899 children and adolescents aged 6–17 years from seven large population-based surveys in China, India, Iran, Korea, Poland, Tunisia, and the United States, which were used to develop the international child BP references. Table 2 shows the characteristics of these surveys described in detail elsewhere [9–16]. Briefly, data from India, Poland, and Tunisia came from single national cross-sectional surveys, while data from China, Iran, Korea, and the United States were pooled from several national cross-sectional surveys. For each survey, all participants and their parents provided a written informed consent, except in Tunisia, where parents provided a verbal informed consent. All surveys had been approved by their respective Institutional Ethics Review Boards.

Blood pressure values were measured with a mercury sphygmomanometer by trained examiners based on standard protocols in each of the seven countries and were obtained after children had been seated for at least 5–10 min. Systolic BP was defined by the onset of the first Korotkoff sound and DBP by the fifth Korotkoff sound (K5). Children with DBP equal to 0 mm Hg were excluded. In five countries (China, India, Korea, Poland, and the United States), three BP values were available, and the last two values were averaged for data analysis. In Iran and Tunisia, two BP values were available, and the mean of both values was used for data analysis. Weight and height were measured for all participants in light clothing without shoes. Body mass index was calculated as weight divided by height squared (kg/m^2).

Table 2 Performance of the height-specific 95th percentile BP cutoffs for the identification of high BP in children and adolescents from the pooled data based on 10 study populations

	Boys						Girls					
	AUC (95% CI)	Sensitivity, %	Specificity, %	PPV, %	NPV, %	Kappa coefficient	AUC (95% CI)	Sensitivity, %	Specificity, %	PPV, %	NPV, %	Kappa coefficient
Total	0.94 (0.94–0.94)	88.5	99.3	93.9	98.5	0.90	0.91 (0.91–0.92)	82.9	99.7	97.3	97.8	0.88
Age												
6–11 years	0.94 (0.94–0.95)	89.0	99.3	94.1	98.5	0.90	0.94 (0.93–0.95)	88.5	99.5	96.3	98.5	0.91
12–17 years	0.94(0.93–0.94)	88.1	99.2	93.8	98.5	0.90	0.89 (0.89–0.90)	78.8	99.8	98.1	97.4	0.86
Type of high BP												
High SBP	0.94 (0.94–0.95)	89.3	99.2	92.0	98.9	0.90	0.91 (0.91–0.92)	82.5	99.7	96.1	98.3	0.88
High DBP	0.92 (0.92–0.93)	84.4	100.0	98.7	99.2	0.91	0.91 (0.91–0.92)	92.5	100.0	99.3	99.1	0.90
Weight status												
Normal weight	0.94 (0.93–0.94)	88.3	99.4	93.5	98.9	0.90	0.91 (0.90–0.91)	81.9	99.8	97.1	98.3	0.88
Overweight or obese	0.94 (0.93–0.94)	88.8	98.5	94.6	96.8	0.89	0.92 (0.91–0.93)	84.4	99.4	97.5	95.8	0.88

SBP systolic blood pressure, *DBP* diastolic blood pressure, *AUC* area under the curve, *PPV* positive predictive value, *NPV* negative predictive value

Validation data

The validation data included 70,072 participants aged 6–17 years from three other population-based surveys in China, Poland, and Seychelles. These surveys have been described elsewhere [17–19]. Briefly, data from China came from a cross-sectional survey in Jinan, while data from Poland and Seychelles came from national cross-sectional surveys. Informed consent was obtained from the participants and their parents/guardians. These surveys had been approved by the ethical research committee of each country.

BP values from China were measured using an Omron device (HEM-7012) [20]. BP values from Poland were obtained using a Datascope Accutor Plus device (Datascope Corp., Fairfield, New Jersey, USA) [21]. BP values from Seychelles were measured using an Omron device (M5) [22]. All oscillometric devices had been clinically validated [20–22], although the device used in Seychelles was validated for adults but not for children. Three BP readings were available in China and Poland, and the mean value of the last two readings was used for data analysis. Two BP values were available in Seychelles, and the mean of the two readings was used for data analysis.

Definition of elevated BP, high BP, and obesity

Elevated BP was defined as SBP/DBP ≥90th BP percentile (or ≥120/80 mm Hg), and high BP was defined as SBP/DBP ≥95th BP percentile, using the sex-, age-, and height-specific international BP table as the gold standard [3]. Elevated and high BP was re-defined using cutoffs of the simple table in Table 1. Overweight and obesity were defined based on the criteria from the International Obesity Task Force [23].

Statistical analysis

Performance of the simple table, compared to the reference international table, was assessed using the following statistics: area under the curve (AUC), sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Kappa coefficients were also calculated to assess the agreement between the two tables. These validity indices were assessed both internally (i.e., in the seven populations from which the simple table was developed) and externally (i.e., in three other populations). All analyses were performed using SAS 9.4 (SAS Institute, Cary, NC).

Results

Characteristics of the 10 population-based surveys are displayed in Table S1. A total of 12,8971 children and adolescents aged 6–17 years with complete data were used in this study. In the derivation data, the sample sizes ranged from 1777 in Tunisia to 16,613 in Iran. The prevalence of high BP (i.e., ≥ the 95th BP percentile) ranged from 4.4% in Korea to 18.0% in India. The prevalence of elevated BP (i.e., ≥ the 90th BP percentile) ranged from 13.5% in Korea to 36.1% in Tunisia. The prevalence of combined overweight and obesity ranged from 8.2% in China to 37.5% in the United States. In the validation data, the sample sizes ranged from 7845 in China to 45,459 in Seychelles. The prevalence of high BP ranged from 12.0% in Poland to 15.0% in China. The prevalence of elevated BP ranged from 25.0% in Seychelles to 28.1% in China. The prevalence of combined overweight and obesity ranged from 18.6% in Seychelles to 35.8% in China.

In the pooling data of 10 population-based studies, the simple table performed excellently for identifying high BP compared to the international BP reference table, with high values in boys/girls for AUC (0.94/0.91), sensitivity (88.5%/82.9%), specificity (99.3%/99.7%), PPV (93.9%/97.3%), NPV (98.5%/97.8%), and Kappa coefficients (0.90/0.88) (Table 2). The simple table also performed excellently for predicting elevated BP with similarly high values in boys/girls for AUC (0.98/0.97), sensitivity (97.3%/93.6%), specificity (99.2%/99.5%), PPV (97.6%/97.9%), NPV (99.1%/98.3%), and Kappa coefficients (0.97/0.95) (Table 3). The results were similar according to age group, type of BP status and weight status for both high BP (Table 2) and elevated BP (Table 3). The performance of the simple table to predict high BP (Table S2) and elevated BP (Table S3) was also similar in each of the 10 countries.

Discussion

In this study, we showed that a simple table based on height only predicted elevated BP and high BP excellently, compared to the international reference table based on sex, age, and height in children and adolescents aged 6–17 years. The simple table included only 16 SBP and DBP height cutoffs, compared to 336 SBP and DBP cutoffs in the international BP table used as the reference.

The standard BP guidelines for children and adolescents based on sex, age, and height include several hundreds of BP cutoffs to predict elevated BP and high BP, which makes them cumbersome to use in clinical practice. Electronic clinical decision supports [24–26] may overcome the difficulty of diagnosing high BP in children and adolescents by using complex algorithms, but they require the use of electronic medical files, which not all clinicians are willing to use. Hence, a simpler algorithm (e.g., a table with only a few BP cutoffs) can help clinicians

Table 3 Performance of the height-specific 90th percentile BP cutoffs for the identification of elevated BP in children and adolescents from the pooled data based on 10 study populations

	Boys						Girls					
	AUC (95% CI)	Sensitivity, %	Specificity, %	PPV, %	NPV, %	Kappa coefficient	AUC (95% CI)	Sensitivity, %	Specificity, %	PPV, %	NPV, %	Kappa coefficient
Total	0.98 (0.98–0.98)	97.3	99.2	97.6	99.1	0.97	0.97 (0.96–0.97)	93.6	99.5	97.9	98.3	0.95
Age												
6–11 years	0.96 (0.96–0.96)	93.6	98.5	93.9	98.4	0.92	0.96 (0.95–0.96)	92.4	99.0	95.8	98.1	0.93
12–17 years	0.99 (0.99–0.99)	99.0	99.7	99.3	99.6	0.99	0.97 (0.97–0.97)	94.4	99.8	99.2	98.4	0.96
Type of elevated BP												
Elevated SBP	0.98 (0.98–0.99)	97.8	99.0	96.6	99.4	0.96	0.97 (0.96–0.97)	93.6	99.4	96.9	98.7	0.94
Elevated DBP	0.97 (0.97–0.98)	94.9	100.0	99.8	99.4	0.97	0.96 (0.96–0.97)	92.7	100.0	99.4	99.2	0.96
Weight status												
Normal weight	0.98 (0.98–0.99)	97.5	99.3	97.4	99.3	0.97	0.97 (0.96–0.97)	93.9	99.5	97.7	98.7	0.95
Overweight or obese	0.98 (0.98–0.98)	96.9	98.6	98.0	97.7	0.96	0.96 (0.96–0.97)	93.2	99.2	98.5	96.3	0.94

SBP systolic blood pressure, *DBP* diastolic blood pressure, *AUC* area under the curve, *PPV* positive predictive value, *NPV* negative predictive value identify children and adolescents with high BP. A simple table can also help children and their parents appreciate the gap between their actual and desired BP levels.

There have been several attempts to simplify the detection of high BP in children and adolescents, compared to the historic and broadly used U.S. table based on sex, age, and height, which includes as many as 476 BP cutoffs [1], such as the 90th percentile BP cutoffs by sex and age at the 5th percentile of height [27] and BP-to-height ratios [28]. However, these methods have shown limited positive predictive value (i.e., a large proportion of false positive cases, ~50%), and therefore require substantial work for screening programs to check the BP readings of all the positive cases against complex age-, sex-, and height-specific gold standard guidelines, in addition to causing unnecessary anxiety or stress for children and their guardians. The higher PPV (>90%) of our simple table by height will facilitate the screening process in clinical practice.

Height is strongly associated with BP in children and adolescents, independently of sex and age [29]. In 2013, Chiolero et al. developed a simple table to predict high BP in children and adolescents based on height only [8]. That table, which includes only 22 BP cutoffs, performed very well compared to the U.S. Fourth Report table, with a PPV as high as 0.90 [7, 8]. In the present study, we showed that a similar simple table based on height only performed nearly identically as well as the international reference table based on sex, age, and height, with a PPV ≥0.95. However, even a high PPV of 95% means that approximately 5% of children will be misclassified as having high BP while actually having normal BP. Thus, the simple table is best suited for screening purposes, and perhaps, particularly when a pediatrician is not available, such as school screening programs led by school nurses, or in similar situations.

It should be noted that all currently available reference guidelines to assess elevated or high BP in children and adolescents are based on normative data, and the significance of elevated or high BP in children is subsequently arbitrary [30]. However, several studies have shown associations between elevated BP in children defined using the pediatric BP percentile values and hypertension-related outcomes in adulthood (such as arterial stiffness or high carotid intima-media thickness), including studies that have used the international reference table based on sex, age, and height [31, 32]. In addition, cutoffs for high BP in children up to age 17 (based on the sex-, age- and height-specific distribution of BP) may not exactly correspond to high BP (usually ≥140/90 mmHg) as defined based on outcome data used in adults starting at age 18.

The strengths of our study include large sample sizes, data from several countries on different continents, a high quality of data, and validation of the simple table in external populations, which makes our findings generalizable to other populations. However, several limitations should also be considered. First, BP was measured at only one visit in the present study, while a definite diagnosis of hypertension should be established based on BP readings taken at several visits in view of BP variability over time [33, 34]. It is therefore expected that the prevalence of elevated and high BP will be substantially higher based on BP readings taken at 1 visit only, compared to BP readings taken at several visits [33, 34]. Higher BP on one vs several visits is related to the habituation of individuals to subsequent BP readings and to the regression to the mean phenomenon. Of note, the overestimation of the true prevalence of hypertension of our data does not alter the validity of the simple table. Second, children aged <6 years were not considered. However, some guidelines suggest that BP should be assessed from the age of 3 years onwards [1]. Third, the oscillometric device used to measure BP in Seychelles was validated in adults but not in children or adolescents. Fourth, given that the simple table has a higher sensitivity (>93%) for identifying elevated BP than for identifying high BP (>82%), the simple table may be particularly useful for screening elevated BP vs high BP. Fifth, we categorized a child's height using 10 cm units, which may be fairly broad. Further studies should assess the performance of height-based tables using other height categories.

Conclusions

The present study shows that a simple table based on height only, which includes only 16 BP cutoffs, performed virtually as well as the reference table based on sex, age, and height that includes more than 300 BP cutoffs. Because it is much more convenient to use than the reference table, the simple table could contribute to improved detection and control of high BP among children and adolescents in diverse populations.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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