Performance of User-Friendly Screening Tools for Elevated Blood Pressure in Children

Chunming Ma, MD, Rui Wang, MD, Yue Liu, BD, Qiang Lu, BD, Na Lu, MD, Yiming Tian, PhD, Xiaoli Liu, MD, Fuzai Yin, MD

abstract

CONTEXT: Hypertension is frequently undiagnosed in children. Several methods have been developed to simplify screening for elevated blood pressure (BP) in children.

OBJECTIVE: to assess the performance of different screening tools in identifying elevated BP in the pediatric population.

DATA SOURCES: Data sources such as PubMed, Embase, Web of Science, Cochrane, and Scopus were searched up to March 2016.

STUDY SELECTION: Studies providing measures of diagnostic performance of screening tools and that used age-, sex-, and height-specific BP percentile as the reference standard were included.

DATA EXTRACTION: Data regarding the population, screening tools used to define elevated BP, and diagnostic criteria of BP were extracted. Available data on true-positive, false-positive, true-negative, and false-negative results were also extracted to construct a 2 × 2 contingency table.

RESULTS: A total of 16 eligible studies that evaluated 366 321 children aged 3 to 18 years were included in the meta-analysis. Nine screening tools were included in this study, in which the BP-to-height ratio, the modified BP-to-height ratio, and tables based on age categories had the highest sensitivities (97–98%) but moderate specificities (71–89%).

LIMITATIONS: Limitations included that BP measurements in most studies were based on 1 visit only and there was heterogeneity between the studies.

CONCLUSIONS: Several user-friendly screening tools could improve the screening of elevated BP in the pediatric population.

Department of Endocrinology, First Hospital of Qinhuangdao, Qinhuangdao, China

Dr Yin conceptualized and designed the study; Dr Ma extracted data from the primary studies, analyzed the data, and drafted the initial manuscript; Dr Wang extracted data from the primary studies and analyzed the data; Drs Y. Liu, Q. Lu, N. Lu, Tian, and X. Liu revised the manuscript critically for important intellectual content; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

DOI: 10.1542/peds.2016-1986

Accepted for publication Nov 7, 2016

Address correspondence to Fuzai Yin, MD, Department of Endocrinology, First Hospital of Qinhuangdao, No. 258 Wenhua Rd, Qinhuangdao, 066000, Hebei Province, China. E-mail: yinfuzai62@163.com

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: No external funding.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

To cite: Ma C, Wang R, Liu Y, et al. Performance of User-Friendly Screening Tools for Elevated Blood Pressure in Children. *Pediatrics.* 2017;139(2):e20161986

Hypertension is a global health burden and an important risk factor for stroke, cardiovascular disease, end-stage renal disease, and overall mortality in adults.[1] Childhood hypertension has become an important health issue due to its increasing prevalence, now affecting 3% to 5% of children, and its risk for end-organ damage.[2–4]

The American Academy of Pediatrics recommends that blood pressure (BP) measurements be taken at all pediatric visits for the health care of children >3 years old.[5] However, hypertension is frequently undiagnosed.[6] The diagnostic criteria in the US Fourth Report include age-, sex-, and height-specific percentiles of systolic BP (SBP) and diastolic BP (DBP).[5] The diagnostic criteria in Germany and of the European Society of Hypertension and international BP references are also based on age-, sex-, and height-specific percentiles.[7–9] The guidelines of the United States and Europe all recommend that elevated BP must be confirmed on repeated measures before a child is characterized as having hypertension. Several methods to simplify the screening of elevated BP in children have been developed and could improve the detection of elevated BP in children. BP-to-height ratio (BPHR) is a simple formula: BPHR = BP/height.[10] Diagnostic criteria formulas are simple equations relating BP thresholds to age.[11] The table in Mitchell et al[12] corresponds to 5 age categories, independent of sex and height. The table in Kaelber and Pickett[13] corresponds to age and sex, independent of height, and the tables in Chiolero et al[14] and Ardissino et al[15] represent height-specific BP thresholds. This systematic review aimed to meta-analyze the performance of different screening tools for identifying elevated BP in children and adolescents.

METHODS

Search Strategy and Eligibility Criteria

A systematic review of the published articles was performed in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The predefined inclusion criteria for study selection were as follows: the study must have (1) assessed the performance of screening tools to identify elevated BP in children and adolescents aged 0 to 18 years, (2) provided a 2 × 2 diagnostic table to allow for meta-analysis or information to calculate these values, and (3) used an age-, sex-, and height-specific BP percentile as the gold standard. Prehypertension was defined as the age-, sex-, and height-specific 90th percentile or ⩾120/80 mm Hg BP. Hypertension was defined as the age-, sex-, and height-specific 95th percentile. Editorials, reviews, and abstracts from conference proceedings were excluded. The study selection was limited to English-language studies and studies in humans only.

A systematic search was conducted in the bibliographic databases, including PubMed, Embase, Web of Science, Cochrane, and Scopus from inception to March 31, 2016. First, a categorical search was conducted that used the following 3 key word phrases: (1) hypertension or elevated BP or their synonyms (eg, abnormal BP), (2) children or adolescents or their synonyms (eg, teenage), and (3) screening or its equivalent words (eg, sensitivity and specificity). Second, categories “1” to “3” were combined by using “and” and the duplicates were removed. In addition, the related literature and reference lists of the identified articles were searched for relevant publications.

Study Selection and Quality Assessment

Irrelevant articles were eliminated from the primary search on the basis of the information in the title and abstract. Once the studies were identified by the information in the titles and abstracts, full articles were obtained for all relevant studies. Two reviewers (C.M. and R.W.) independently reviewed the full articles obtained from the search for relevance. All studies that did not meet the inclusion criteria or that met the exclusion criteria were removed. Disagreements between the 2 reviewers regarding study inclusion were resolved through face-to-face discussion of the full-text assessment. Eligible studies were further reviewed.

The methodologic quality of each study was assessed by using a checklist based on the QUADAS (Quality Assessment for Studies of Diagnostic Accuracy) tool,[16] which enabled the reviewers to evaluate the quality of the studies. Disagreements between the reviewers on individual items were resolved through a consensus meeting with a third reviewer (F.Y.).

Data Extraction

Data were independently extracted from the primary studies by 2 reviewers (C.M. and R.W.). Data regarding the population, screening tools used to define elevated BP, and BP diagnostic criteria were extracted. Available data on true-positive, false-positive, true-negative, and false-negative results were extracted to construct a 2 × 2 contingency table.

Data Synthesis and Statistical Analysis

From the extracted data, which were arranged in 2 × 2 contingency tables, the pooled summary statistics were computed for sensitivities, specificities, likelihood ratios, and diagnostic odds ratios (DORs) to estimate the diagnostic performance.

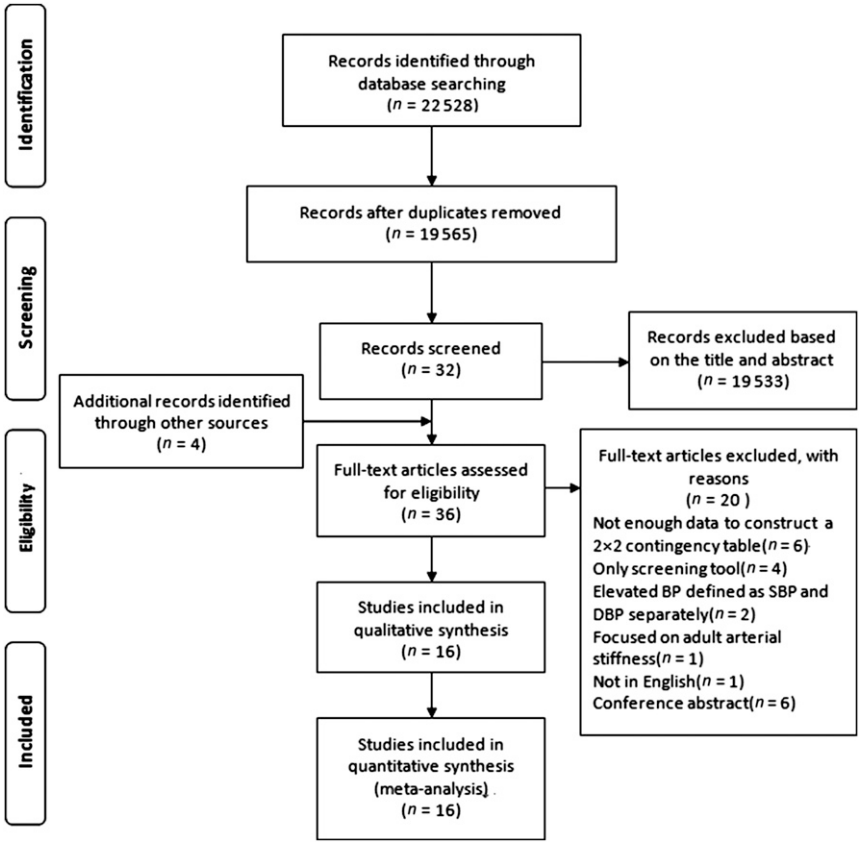

FIGURE 1
Flowchart of the selection of studies and specific reasons for exclusion from the meta-analysis.

All statistics were reported as point values with 95% confidence intervals (CIs). The heterogeneity of all diagnostic test parameters was evaluated with the inconsistency index (I^2). The I^2 statistic is defined as the percentage of variability due to heterogeneity beyond that from chance; values >50% represent the possibility of substantial heterogeneity.

Multivariable meta-regression was performed to explain the heterogeneity. The following confounders were chosen: (1) diagnostic criteria used to assess elevated BP, (2) BP measurement methods, (3) number of office visits, (4) region, (5) source of study population, (6) sample size, and (7) quality assessment score.

Studies were grouped on the basis of the diagnostic criteria used to assess elevated BP according to (1) the definition of US Fourth Report or (2) the European criteria. BP measurement methods were grouped according to auscultatory or oscillometric methods; number of office visits were categorized as 1 visit or "other"; region of the study population was categorized as North America, South America, Europe, Asia, or Africa; and source of the study population was categorized as from a school or community or from a clinic or hospital. Finally, the studies were categorized into 2 subgroups on the basis of the QUADAS score (<10 and ≥10).

Summary receiver operating characteristic curves were also constructed to express the test parameter results as DORs. The diagnostic threshold (cutoff) bias was also evaluated as a cause of between-study heterogeneity. Begg's test and Egger's test were conducted to examine the possible publication bias of the studies regarding the performance of screening tools in detecting elevated BP. Analyses were performed by using the Meta-Disc 1.4 statistical software (Unit of the Clinical Biostatistics team of the Ramony Cajal Hospital; Madrid, Spain) and Stata version 12.0 software (StataCorp, College Station, TX).

RESULTS

Figure 1 summarizes the selection process of the studies. In total, 22 528 references were obtained by using PubMed, Embase, Web of Science, Cochrane, and Scopus. An additional 4 full-text articles were included after scanning the related literature and reference lists of the studies selected for inclusion. Finally, a total of 16 studies were included in this review.[10,12,14,17–29]

Supplemental Table 4 shows details of these 16 studies. Studies were conducted between 2011 and 2016 in 8 different countries, including 2 from Asia, 1 from Africa, 2 from North America, 1 from South America, and 2 from Europe. The population size of the studies ranged from 107 to 197 191 participants. The total number of children and adolescents was 366 321 in the meta-analysis. Seven studies assessed only the performance of screening tools in identifying hypertension. Nine studies assessed the performance of screening tools in identifying both prehypertension and hypertension. The quality of the included articles is summarized in Supplemental Table 4. Details of the screening tools are shown in Table 1.

Prehypertension (Defined as Age-, Sex-, and Height-Specific 90th Percentile or ≥120/80 mm Hg)

Supplemental Table 5 shows that the pooled sensitivity to detect prehypertension was 0.953 (95% CI: 0.951–0.955) and the pooled

TABLE 1 Formulas and Tables of Different Screening Methods for Elevated BP in Children and Adolescents

BPHR				
SBPHR = SBP (mm Hg)/height (cm)				
DBPHR = DBP (mm Hg)/height (cm)				
MBPHR				
Modified SBPHR = SBP (mm Hg)/(height [cm] +7 × [13 − age in years])				
Modified DBPHR = DBP (mm Hg)/(height [cm] + 7 × [13 − age in years])				
	Age, y	Formula		
Diagnostic criteria formulas				
BP, mm Hg				
SBP	Between 1 and 17	100 + (age in years × 2)		
DBP	Between 1 and 10	60 + (age in years × 2)		
	Between 11 and 17	70 + (age in years)		
	SBP, mm Hg	DBP, mm Hg		
Mitchell et al[12] table				
Age, y				
3 to <6	≥100	>60		
6 to <9	≥105	>70		
9 to <12	≥110	>75		
12 to <15	≥115	>75		
≥15	≥120	≥80		
	Height range, cm	SBP, mm Hg	DBP, mm Hg	
Chiolero et al[14] table				
Height category, cm				
80	<85	104	61	
90	85–94	107	65	
100	95–104	110	68	
110	105–114	112	72	
120	115–124	114	76	
130	125–134	117	78	
140	135–144	120	80	
150	145–154	123	81	
160	155–164	128	83	
170	165–174	131	85	
180	>175	136	87	
	Boys, mm Hg		Girls, mm Hg	
	SBP	DBP	SBP	DBP
Kaelber and Pickett[13] table				
Age, y				
3	100	59	100	61
4	102	62	101	64
5	104	65	103	66
6	105	68	104	68
7	106	70	106	69
8	107	71	108	71
9	109	72	110	72
10	111	73	112	73
11	113	74	114	74
12	115	74	116	75
13	117	75	117	76
14	120	75	119	77
15	120	76	120	78
16	120	78	120	78
17	120	80	120	78
≥18	120	80	120	80
	Boys, mm Hg		Girls, mm Hg	
	SBP	DBP	SBP	DBP
Ardissino et al[15] table				
Height, cm				
55	97	70	99	70
60	106	68	108	68
70	110	69	111	70
80	104	59	105	60
90	108	63	107	64

TABLE 1 Continued

BPHR				
100	110	67	108	68
110	113	73	110	72
120	115	79	113	76
130	117	82	117	79
140	120	83	119	81
150	124	85	123	83
160	127	85	127	85
170	127	85	127	85
180	127	85	127	85
190	127	85	—	—

—, no reference.

specificity was 0.784 (95% CI: 0.783–0.786). The positive likelihood ratio (LR) was 6.826 (95% CI: 5.309–8.778), the negative LR was 0.077 (95% CI: 0.035–0.170), and the DOR was 105.93 (95% CI: 50.544–222.01).

Heterogeneity was observed across studies (I^2 = 99.4%–99.9%). The Spearman correlation coefficient (Logit [sensitivity] versus Logit [1 – specificity]) was 0.284 (P = .325). The diagnostic threshold (cutoff) bias did not appear to be a cause of heterogeneity. In multivariable meta-regression, the source of study population (from a school or community versus from a clinic or hospital) could explain the source of between-study heterogeneity (DOR: 13.37; 95% CI: 1.78–100.46; P = .017). The Begg's and Egger's tests did not reveal a significant publication bias (P = .511 and .758).

Hypertension (Defined as Age-, Sex-, and Height-Specific 95th Percentile)

Supplemental Table 5 shows that the pooled sensitivity to detect hypertension was 0.950 (95% CI: 0.948–0.953) and the pooled specificity was 0.856 (95% CI: 0.855–0.857); the positive LR was 11.233 (95% CI: 9.113–13.846), the negative LR was 0.066 (95% CI: 0.040–0.109), and the DOR was 216.18 (95% CI: 120.65–387.38).

Heterogeneity was observed across studies (I^2 = 98.3–99.9%). The Spearman correlation coefficient (Logit [sensitivity] versus Logit [1 – specificity]) was 0.522 (P = .004). This finding revealed the evidence supporting the diagnostic threshold (cutoff) bias as a cause of heterogeneity. In multivariable meta-regression, no variables could explain the source of between-study heterogeneity (all P > .05). The Begg's and Egger's tests did not reveal a significant publication bias (P = .399 and .780).

Performance of Different Screening Tools

Table 2 shows the performance of the different screening tools. In 2 reference standards, BPHR, modified BPHR (MBPHR), and the Mitchell et al[12] and Kaelber and Pickett[13] tables had the best sensitivities (97–98%) and moderate specificities (71–89%). Diagnostic criteria formulas and the Ardissino et al[15] and Chiolero et al[14] tables (only in the BP 95th percentile) had the best specificities (98–100%) and low sensitivities (57–85%). The areas under the curve for BPHR, MBPHR, diagnostic criteria formulas, and the Kaelber and Pickett and Chiolero et al tables were all >0.9 for screening hypertension.

Table 3 shows the 5 most "sensitive" and most "specific" screening tools. The sensitivities and specificities of the Kaelber and Pickett table, the Mitchell et al table, and MBPHR all ranked in the top 5 for identifying prehypertension. The sensitivities and specificities of BPHR, MBPHR, and the Ardissino et al table all ranked in the top 5 for identifying hypertension.

DISCUSSION

This meta-analysis found that the user-friendly screening tools had high pooled sensitivity and moderate pooled specificity in identifying elevated BP in children and adolescents. When the performances of different screening tools were analyzed separately, BPHR, MBPHR, and the Mitchell et al and Kaelber and Pickett tables had the best sensitivities. The diagnostic criteria formulas and the Ardissino et al and Chiolero et al tables had the best specificities.

In 2011, Lu et al[10] evaluated, for the first time, the performance of BPHR for identifying elevated BP in ethnic Han adolescents. More recently, 2 meta-analyses showed that BPHR performed well for identifying elevated BP in children and adolescents, independently of sex, age, and ethnicity groups.[30,31] This study suggested that the SBP-to-height ratio (SBPHR) and DBP-to-height ratio (DBPHR) should be used together. SBPHR and DBPHR were used to identify elevated SBP and DBP, respectively. The combination of SBPHR+DBPHR was then applied to identify elevated BP. The sensitivities decreased significantly when SBPHR or DBPHR was used as 2 separate screening tools to identify elevated BP.[18,20] Some researchers believed that the

TABLE 2 Sensitivities, Specificities, LRs, and DORs of Screening Tools for Identifying Elevated BP

Screening Tools	*N*	Sensitivity (95% CI)	Specificity (95% CI)	Positive LR (95% CI)	Negative LR (95% CI)	DOR (95% CI)	Area Under Curve (SE)
Prehypertension[a]							
BPHR	4	0.97 (0.97–0.97)	0.73 (0.73–0.73)	3.63 (3.60–3.66)	0.04 (0.04–0.04)	87.62 (82.09–93.51)	0.87 (0.04)
SBPHR	1	0.77 (0.74–0.80)	0.77 (0.76–0.78)	3.35 (3.14–3.57)	0.30 (0.26–0.34)	11.20 (9.30–13.49)	—
DBPHR	1	0.73 (0.70–0.76)	0.73 (0.72–0.74)	2.71 (2.54–2.88)	0.37 (0.33–0.42)	7.34 (6.15–8.75)	—
MBPHR	2	0.97 (0.96–0.97)	0.88 (0.88–0.88)	8.14 (7.98–8.29)	0.04 (0.03–0.04)	213.96 (193.88–236.13)	—
Diagnostic criteria formulas	1	0.57 (0.53–0.61)	1.00 (1.00–1.00)	286.86 (153.84–534.88)	0.43 (0.39–0.47)	663.62 (349.59–1259.71)	—
Mitchell et al[12] table	2	0.98 (0.97–0.99)	0.78 (0.77–0.79)	4.44 (4.22–4.67)	0.03 (0.02–0.04)	160.97 (99.12–261.42)	—
Kaelber and Pickett[13] table	2	0.98 (0.97–0.99)	0.88 (0.88–0.89)	8.47 (7.85–9.13)	0.02 (0.01–0.04)	355.33 (215.01–587.25)	—
Ardissino et al[15] table	1	0.63 (0.59–0.67)	1.00 (1.00–1.00)	318.54 (170.99–593.44)	0.37 (0.33–0.41)	862.50 (453.87–1639.02)	—
Hypertension[b]							
BPHR	7	0.98 (0.98–0.98)	0.83 (0.83–0.83)	5.79 (5.73–5.84)	0.02 (0.02–0.03)	259.25 (229.30–293.10)	0.97 (0.02)
SBPHR	2	0.81 (0.77–0.84)	0.81 (0.80–0.82)	4.28 (4.03–4.54)	0.24 (0.19–0.29)	18.13 (14.20–23.14)	—
DBPHR	2	0.76 (0.72–0.80)	0.72 (0.72–0.73)	2.75 (2.59–2.93)	0.33 (0.28–0.39)	8.32 (6.64–10.41)	—
MBPHR	3	0.98 (0.98–0.98)	0.89 (0.89–0.90)	9.28 (9.10–9.47)	0.02 (0.02–0.03)	409.57 (348.12–481.88)	0.99 (0.02)
Diagnostic criteria formulas	3	0.78 (0.75–0.81)	0.99 (0.99–0.99)	77.01 (62.83–94.39)	0.22 (0.20–0.26)	343.04 (263.84–446.01)	0.99 (0.01)
Mitchell et al[12] table	3	0.98 (0.97–0.99)	0.71 (0.70–0.72)	3.41 (3.30–3.54)	0.03 (0.02–0.05)	122.04 (70.34–211.76)	0.89 (0.06)
Chiolero et al[14] table	3	0.83 (0.82–0.84)	0.99 (0.99–0.99)	99.73 (88.23–112.73)	0.17 (0.16–0.18)	584.82 (501.32–682.24)	0.96 (0.05)
Kaelber and Pickett[13] table	4	0.98 (0.97–0.99)	0.78 (0.77–0.78)	4.39 (4.22–4.56)	0.02 (0.01–0.04)	198.50 (118.88–331.48)	0.94 (0.02)
Ardissino et al[15] table	2	0.85 (0.82–0.88)	0.98 (0.98–0.99)	56.23 (46.07–68.63)	0.15 (0.12–0.18)	374.43 (276.91–506.30)	—

—, no reference.

[a] Defined as age-, sex-, and height-specific 90th percentile or ⩾120/80 mm Hg.

[b] Defined as age-, sex-, and height-specific 95th percentile.

performance of BPHR was lower in younger children compared with adolescents.[23] Its sensitivity and specificity were lower in younger children when compared with adolescents.[32] Therefore, Mourato et al developed the MBPHR.[23] They reported that MBPHR could improve the accuracy of screening elevated BP in childhood, and the index was better than BPHR.[23] In the present meta-analysis, BPHR and MBPHR both showed good performance, with high sensitivities and specificities for identifying elevated BP in children and adolescents. The results were consistent with those of another study.[30] However, the formula for MBPHR is more complicated.

Mitchell et al[12] produced a table with only 10 BP thresholds. The Mitchell et al table started at age 3 years and increased in increments of 3 years for a total of 5 age groups. The cutoff values of both SBP and DBP decreased below the lowest 95th percentile value in all cases and close to the lowest 90th percentile value. The Kaelber and Pickett table used the lower limit of height (fifth percentile) in the abnormal BP range (90th percentile) for a given sex and age, and its application reduced the number of thresholds from 476 to 64.[13] The Mitchell et al table and the Kaelber and Pickett table had the same sensitivities (98%), but did not reach 100%, which is because the fifth percentile of height was not the lowest BP cutoff value.[5] The BP percentiles with height percentiles (the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles only) are given in US guidelines.[5] The BP percentiles of children with these height percentiles can be searched through the BP tables. For children with height percentiles other than these, BP percentiles should be calculated following 4 complicated steps. The cutoff values of BP decline with decreasing height percentiles.[5] The cutoff values for children with

height less than the fifth percentile may be lower than the cutoff values of the Mitchell et al and Kaelber and Pickett tables. Children with height less than the fifth percentile may be underrecognized. The Mitchell et al table represents to 5 age categories, whereas the Kaelber and Pickett table represents age. The Kaelber and Pickett table has better specificities than the Mitchell et al table. The Mitchell et al table is simpler than the Kaelber and Pickett table. The follow-up study found that the Mitchell et al and Kaelber and Pickett tables predicted the risk of adult high arterial stiffness as well as age-, sex-, and height-specific percentiles. These simple screening tools could be used for identifying pediatric subjects at risk and for intervening to improve adult cardiovascular outcomes.[33]

The diagnostic criteria formulas were created on the basis of a regression analysis of the 95th BP percentile of a 1987 US Task Force report, which considered the 50th percentile for height in both sexes.[11] The 95th BP percentiles of the 1987 and 2004 US Task Force reports were similar.[5,34] Therefore, the diagnostic criteria formulas are not appropriate screening methods for prehypertension in children. Pooled results from the diagnostic criteria formulas revealed that sensitivity was only 57% for screening children with prehypertension, which suggests that more than two-fifths of children were undiagnosed. The pooled sensitivity of the diagnostic criteria formulas was 78% for screening children with hypertension. The cutoff values increased with percentile of height. The diagnostic criteria formulas might underdiagnose children with height less than the 50th percentile.

The Chiolero et al table selected the mean of BP values corresponding to the 95th BP percentile US Task Force report of different age, sex, and height categories.[14] Like the diagnostic criteria formulas, Chiolero et al's table will also result in underdiagnosis because the cutoff values represented the mean of the gold standard. The pooled sensitivity of the Chiolero et al table was 83% for screening children with BP ≥95th percentile. Compared with the Chiolero et al table, the Ardissino et al table had more height categories and sex-dependent cutoff values.[15] However, their performance was similar.

TABLE 3 Five Most "Sensitive" and Most "Specific" Screening Tools

Rank	Prehypertension		Hypertension	
	Most "Sensitive" Screening Tools	Most "Specific" Screening Tools	Most "Sensitive" Screening Tools	Most "Specific" Screening Tools
1	Kaelber and Pickett[13] table	Diagnostic criteria formulas	Kaelber and Pickett[13] table	Diagnostic criteria formulas
2	Mitchell et al[12] table	Ardissino et al[15] table	Mitchell et al[12] table	Chiolero et al[14] table
3	BPHR	Kaelber and Pickett[13] table	BPHR	Ardissino et al[15] table
4	MBPHR	MBPHR	MBPHR	MBPHR
5	SBPHR	Mitchell et al[12] table	Ardissino et al[15] table	BPHR

The results of this meta-analysis revealed that the Mitchell et al table, the Kaelber and Pickett table, BPHR, and MBPHR may be better choices for identifying prehypertension and hypertension in children and adolescents. Low specificity is associated with more false-positive cases, which has important psychological implications in children and their parents and increases the proportion of reexamination.

The current study has some limitations. First, 3 repeated BP measurements are required to confirm the diagnosis of hypertension in children and adolescents. The prevalence of hypertension tends to decrease in subsequent visits,[35] which means that children with hypertension at the first visit may turn out to have normal BP at the second and third visits. However, the BP measurements in most studies were based on 1 visit only. The sensitivity of the diagnostic criteria formulas and the table of Chiolero et al may improve after 3 repeated BP measurements. Because children with a missed diagnosis had slightly elevated BP (BP level relatively close to the 95th percentile), they might not truly have sustained elevated BP. Second, heterogeneity existed between the studies. Although the meta-regression analysis was performed to investigate the sources of heterogeneity, few variables could adequately explain these sources. Third, because the number of some screening tools was only 1 or 2 studies, the receiver operating characteristic curve could not be built for these screening tools.

CONCLUSIONS

As screening tools, the tables proposed by Mitchell et al and Kaelber and Pickett as well as BPHR and MBPHR have high sensitivities. The Mitchell et al and Kaelber and Pickett tables are more suitable for clinics and hospitals because they are more intuitive and user-friendly. Although BPHR and MBPHR need to be computed, they can help physicians when no table is available. Because the BP measurements in most studies were based on 1 visit only, the performance of these screening tools should be confirmed by future studies with the use of 3 office visits.

ABBREVIATIONS

BP: blood pressure
BPHR: blood pressure-to-height ratio
CI: confidence interval
DBP: diastolic blood pressure
DBPHR: diastolic blood pressure-to-height ratio
DOR: diagnostic odds ratio
LR: likelihood ratio
MBPHR: modified blood pressure-to-height ratio
SBP: systolic blood pressure
SBPHR: systolic blood pressure-to-height ratio

REFERENCES

1. Lackland DT, Weber MA. Global burden of cardiovascular disease and stroke: hypertension at the core. *Can J Cardiol*. 2015;31(5):569–571
2. Feber J, Ahmed M. Hypertension in children: new trends and challenges. *Clin Sci (Lond)*. 2010;119(4):151–161
3. Rosner B, Cook NR, Daniels S, Falkner B. Childhood blood pressure trends and risk factors for high blood pressure: the NHANES experience 1988-2008. *Hypertension*. 2013;62(2):247–254
4. Dobson CP, Eide M, Nylund CM. Hypertension prevalence, cardiac complications, and antihypertensive medication use in children. *J Pediatr*. 2015;167(1):92–97, e91
5. National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. *Pediatrics*. 2004;114(2 suppl 4th Report):555–576
6. Hansen ML, Gunn PW, Kaelber DC. Underdiagnosis of hypertension in children and adolescents. *JAMA*. 2007;298(8):874–879
7. 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). Available at: www.pediatrics.org/cgi/content/full/127/4/e978
8. Lurbe E, Cifkova R, Cruickshank JK, et al; European Society of Hypertension. Management of high blood pressure in children and adolescents: recommendations of the European Society of Hypertension. *J Hypertens*. 2009;27(9):1719–1742
9. Xi B, Zong X, Kelishadi R, et al; International Child Blood Pressure References Establishment Consortium. Establishing international blood pressure references among nonoverweight children and adolescents aged 6 to 17 years. *Circulation*. 2016;133(4):398–408
10. Lu Q, Ma CM, Yin FZ, Liu BW, Lou DH, Liu XL. How to simplify the diagnostic criteria of hypertension in adolescents. *J Hum Hypertens*. 2011;25(3):159–163
11. Somu S, Sundaram B, Kamalanathan AN. Early detection of hypertension in general practice. *Arch Dis Child*. 2003;88(4):302
12. 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):22–26
13. Kaelber DC, Pickett F. Simple table to identify children and adolescents needing further evaluation of blood pressure. *Pediatrics*. 2009;123(6). Available at: www.pediatrics.org/cgi/content/full/123/6/e972
14. Chiolero A, Paradis G, Simonetti GD, Bovet P. Absolute height-specific thresholds to identify elevated blood pressure in children. *J Hypertens*. 2013;31(6):1170–1174
15. Ardissino G, Bianchetti M, Braga M; Progetto Child, et al. Recommendations on hypertension in childhood: the Child Project [in Italian]. *Ital Heart J Suppl*. 2004;5(5):398–412
16. Whiting P, Rutjes AW, Reitsma JB, Bossuyt PM, Kleijnen J. The development of QUADAS: a tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews. *BMC Med Res Methodol*. 2003;3:25
17. Lu Q, Ma C, Yin F, Wang R, Lou D, Liu X. Blood pressure-to-height ratio as a screening measure for identifying children with hypertension. *Eur J Pediatr*. 2013;172(1):99–105
18. Kelishadi R, Heshmat R, Ardalan G, et al. First report on simplified diagnostic criteria for pre-hypertension and hypertension in a national sample of adolescents from the Middle East and North Africa: the CASPIAN-III study. *J Pediatr (Rio J)*. 2014;90(1):85–91
19. Xi B, Zhang M, Zhang T, Liang Y, Li S, Steffen LM. Hypertension screening using blood pressure to height ratio. *Pediatrics*. 2014;134(1). Available at: www.pediatrics.org/cgi/content/full/134/1/e106
20. Outdili Z, Marti-Soler H, Simonetti GD, et al. Performance of blood pressure-to-height ratio at a single screening visit for the identification of hypertension in children. *J Hypertens*. 2014;32(5):1068–1074; discussion: 1074
21. Dong B, Wang Z, Wang HJ, Ma J. Blood pressure-to-height ratio for screening prehypertension and hypertension in Chinese children. *J Hum Hypertens*. 2015;29(10):618–622
22. Dong B, Wang Z, Wang HJ, Ma J. Improving hypertension screening in childhood using modified blood pressure to height ratio. *J Clin Hypertens (Greenwich)*. 2016;18(6):557–564
23. Mourato FA, Nadruz W Jr, Moser LR, de Lima Filho JL, Mattos SS. A modified blood pressure to height ratio improves accuracy for hypertension in childhood. *Am J Hypertens*. 2015;28(3):409–413
24. Xi B, Zhang M, Zhang T, Li S, Steffen LM. Simplification of childhood hypertension definition using blood pressure to height ratio among US youths aged 8-17years, NHANES 1999-2012. *Int J Cardiol*. 2015;180:210–213
25. Ma C, Lu Q, Yin F. The performance of modified blood pressure-to-height ratio as a screening measure for identifying children with hypertension. *Clin Exp Hypertens*. 2016;38(2):155–159
26. Zuijdwijk C, Feber J, Murnaghan O, Nakhla M. Detection of hypertension and prehypertension in paediatric patients with type 1 diabetes using a simple blood pressure table. *Paediatr Child Health*. 2013;18(9):461–464

27. Totaro S, Rabbia F, Rabbone I, et al. Comparison among different screening tests for diagnosis of adolescent hypertension. *ISRN Hypertension*. 2013;2013:1–3

28. Mourato FA, Lima Filho JL, Mattos SS. Comparison of different screening methods for blood pressure disorders in children and adolescents. *J Pediatr (Rio J)*. 2015;91(3):278–283

29. Ma C, Liu Y, Liu X, Yin F, Lu Q. Comparison of different screening methods for hypertension in Han adolescents. *Clin Pediatr (Phila)*. 2016;55(4):363–367

30. Yin X, Liu Q, Bovet P, Ma C, Xi B. Performance of blood pressure-to-height ratio as a screening tool for elevated blood pressure in pediatric population: a systematic meta-analysis. *J Hum Hypertens*. 2016;30(11):697–702

31. Ma C, Liu Y, Lu Q, et al. The performance of blood pressure-to-height ratio as a screening measure for identifying children and adolescents with hypertension: a meta-analysis. *Blood Press Monit*. 2016;21(1):43–48

32. Guo X, Zheng L, Li Y, Zhang X, Yu S, Sun Y. Blood pressure to height ratio: a novel method for detecting hypertension in paediatric age groups. *Paediatr Child Health*. 2013;18(2):65–69

33. Aatola H, Magnussen CG, Koivistoinen T, et al. Simplified definitions of elevated pediatric blood pressure and high adult arterial stiffness. *Pediatrics*. 2013;132(1). Available at: www.pediatrics.org/cgi/content/full/132/1/e70

34. National High Blood Pressure Education Program Working Group on Hypertension Control in Children and Adolescents. Update on the 1987 task force report on high blood pressure in children and adolescents: a working group report from the National High Blood Pressure Education Program. *Pediatrics*. 1996;98(4 pt 1):649–658

35. Meng L, Liang Y, Liu J, Hu Y, Yan Y, Mi J. Prevalence and risk factors of hypertension based on repeated measurements in Chinese children and adolescents. *Blood Press*. 2013;22(1):59–64

Performance of User-Friendly Screening Tools for Elevated Blood Pressure in Children

Chunming Ma, Rui Wang, Yue Liu, Qiang Lu, Na Lu, Yiming Tian, Xiaoli Liu and Fuzai Yin

Pediatrics 2017;139;
DOI: 10.1542/peds.2016-1986 originally published online January 5, 2017;

PEDIATRICS®
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Performance of User-Friendly Screening Tools for Elevated Blood Pressure in Children

Chunming Ma, Rui Wang, Yue Liu, Qiang Lu, Na Lu, Yiming Tian, Xiaoli Liu and Fuzai Yin

Pediatrics 2017;139;
DOI: 10.1542/peds.2016-1986 originally published online January 5, 2017;