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Potential Misclassification of Blood Pressure Status in Children and Adolescents With Short or Tall Stature

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Blood pressure (BP) is measured in percentiles that are adjusted for sex, age, and height percentile in children and adolescents. Standard tables for the conversion of BP percentiles do not present exact BP percentile cutoffs for extremes in stature, either short (<5th percentile) or tall (>95th percentile). An algorithm can be used to calculate exact BP percentiles across a range of height *z* scores. We compared values from standard BP tables with exact calculations of BP percentiles to see which were better at identifying hypertension in more than 5,000 children with either short or tall stature. Study subjects were 3–17-year-old patients within HealthPartners Medical Group, an integrated health care delivery system in Minnesota, at any time between 2007 and 2012. Approximately half of the subjects who met the criteria for hypertension using exact calculation would be misclassified as normal using available thresholds in the published BP tables instead of the recommended algorithm, which was not included in the tables.

blood pressure; misclassification; pediatrics

Abbreviations: BP, blood pressure; PPV, positive predictive value; SBP, systolic blood pressure.

Hypertension during childhood and adolescence is a potentially reversible cause of cardiovascular morbidity and mortality (1–3). National guidelines for diagnosing and treating hypertension in children and adolescents developed by a National Heart, Lung, and Blood Institute task force were published in their Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents (hereafter referred to as the Fourth Report) in 2004 and confirmed without significant changes in 2011 (4, 5).

The diagnosis of hypertension in children and adolescents through 17 years of age is based on the standard blood pressure (BP) tables published in the Fourth Report (4). The tables are adjusted for sex, age, and height percentile, with heights represented by distributions between the 5th and 95th percentiles. The Fourth Report BP tables were developed using data from multiple observational studies of more than 80,000 youths. As height increases, the threshold for a hypertensive level of BP (i.e., ≥95th percentile) also increases. However, for extremes in stature (short, <5th percentile; tall, >95th percentile), exact percentile definitions of hypertension are not presented in the Fourth Report BP tables. In a recent survey of more than 100 primary care providers in our health system, 20% of family medicine providers and half of pediatricians reported using the Fourth Report BP tables to assess whether a BP was elevated in a pediatric patient (HealthPartners Medical Group, personal communication, 2015).

The Fourth Report also provides an algorithm for the calculation of an exact BP percentile for children of any sex, age, and height. With the widespread use of electronic health records and online calculators, clinicians are now able to use this algorithm to determine exact BP percentiles. Compared with the Fourth Report BP tables, the algorithm will define hypertension at a lower BP for children with heights less than the 5th percentile; for children with heights higher than the 95th percentile, the algorithm will define hypertension using a higher BP. In the present study, we used the algorithm as the gold standard to define exact levels of hypertension and evaluate the potential misclassification of BP status in short and tall children when using the Fourth Report BP tables.

METHODS

Study population

Study subjects were patients who were 3–17.9 years of age within HealthPartners Medical Group, an integrated health care delivery system in Minnesota. We retrieved all heights and BPs recorded in the electronic health record (Epic, Verona, Wisconsin) during primary care visits from January 1, 2007, to December 31, 2012. Heights were measured in inches using a stadiometer. BPs were measured by trained staff who predominantly used aneroid sphygmomanometers. The sphygmomanometers were recalibrated as needed by the medical group bioengineering services. It is standard operating procedure that all BP measurements be taken with children in the seated position a cuff size appropriate to arm size, consistent with Fourth Report recommendations (4).

Statistical analysis

We excluded children with biologically implausible heights using cutoffs recommended by the Centers for Disease Control and Prevention (6). Age- and sex-specific height percentiles and *z* scores were calculated using the Centers for Disease Control and Prevention SAS code (7). We then selected patients at the height extremes (<5th percentile or >95th percentile) for further analyses. For these children, systolic BP (SBP) percentiles were calculated using 2 methods. First, SBP percentiles were calculated using the Fourth Report BP tables. Second, SBP percentiles were calculated with heights less than the 5th percentile reclassified as the 5th percentile and heights higher than the 95th percentile reclassified as the 95th percentile, similar to how clinicians may use the Fourth Report BP tables to assess BP in short or tall children. Because isolated elevation of diastolic BP is rare in children, we focused these analyses on the classification of SBP.

Consistent with the Fourth Report guidelines, hypertension was defined as having SBPs in the 95th percentile or higher at 3 or more visits. Thus, for comparison of truncated versus exact BP percentiles for the identification of hypertension, we required patients to have at least 3 visits with a recorded BP. In order to determine the degree to which misclassification of hypertensive status might result from using the BP tables, we calculated κ statistics, sensitivity, specificity, and positive predictive value (PPV). The HealthPartners Institutional Review Board reviewed, approved, and monitored the study.

RESULTS

We identified 38,448 patients 3–17.9 years of age with at least 1 BP and height measurement recorded at a primary care visit between January 1, 2007, and December 31, 2012. A total of 6,570 participants had heights either less than the 5th percentile or greater than the 95th percentile (Table 1). Among the 1,800 (4.7% of the total) children with heights less than the 5th percentile, 54% were female and 49% were 3–11 years of age. The mean SBP using the exact algorithm was the 48th percentile. Of 4,770 (12.4% of the total) children with heights greater than the 95th percentile, 45% were female and 55% were 3–11 years of age. The mean SBP using the exact algorithm was 42nd percentile. The correlations between calculated BP percentiles and observed BP percentiles were high; they were 0.98 ($P < 0.0001$) and 0.99 ($P < 0.0001$) for SBP and diastolic BP, respectively, in those below the 5th percentile for height, and 0.99 ($P < 0.0001$) and 0.99 ($P < 0.0001$), respectively, in those above the 95th percentiles for height (data not shown).

When we used the algorithm, 80 (4.4%) participants with heights lower than the 5th percentile had a SBP level in the 95th percentile or higher. However, when we used the lowest threshold available in the Fourth Report BP tables, only half of these children were classified as having a SBP in the 95th percentile or higher (sensitivity = 0.50). When we used the algorithm, 144 (3.0%) children with heights greater than the 95th percentile had a SBP in the 95th percentile or higher.

Table 1. Descriptive Characteristics of Children and Adolescents by Height Percentile ($n = 6{,}570$), HealthPartners Medical Group, 2007–2012

Characteristic	Height Percentile					
	<5th (*n* = 1,800)			≥95th (*n* = 4,770)		
	No.	%	Mean (SD)	No.	%	Mean (SD)
Age of girls, years						
3–11	451	46.7		1,272	59.0	
12–17	514	53.3		884	41.0	
Age of boys, years						
3–11	436	52.2		1,333	51.0	
12–17	399	47.8		1,280	49.0	
SBP percentile using exact height			47.47 (27.75)			42.01 (28.51)
SBP percentile using truncated[a] height			35.07 (26.52)			53.16 (28.72)
DBP percentile using exact height			50.44 (23.89)			47.15 (23.99)
DBP percentile using truncated[a] height			44.69 (23.55)			54.24 (23.79)

Abbreviations: DBP, diastolic blood pressure; SBP, systolic blood pressure; SD, standard deviation.

[a] Height was truncated at less than the 5th percentile or greater than the 95th percentile for age and sex.

Table 2. Comparison Between the Standard Blood Pressure Tables[a] and Exact Calculation to Classify a Single Systolic Blood Pressure as Being in the 95th Percentile or Higher Among Children With Heights Less Than the 5th Percentile or Higher Than the 95th Percentile ($n = 6{,}570$), HealthPartners Medical Group, 2007–2012

Stratum	No. Concordant	No. Classified With Exact Algorithm	No. Classified With BP Tables	κ	95% CI	Sensitivity	95% CI	Specificity	95% CI	PPV	95% CI
Total	184	224	360	0.61	0.57, 0.66	0.82	0.77, 0.87	0.97	0.97, 0.98	0.51	0.46, 0.56
Age 3–11 years	101	119	209	0.60	0.53, 0.66	0.85	0.78, 0.91	0.97	0.96, 0.97	0.48	0.42, 0.55
Age 12–17 years	83	105	151	0.63	0.56, 0.70	0.79	0.71, 0.87	0.98	0.97, 0.98	0.55	0.47, 0.63
Girls	88	103	173	0.62	0.55, 0.69	0.85	0.79, 0.92	0.97	0.97, 0.98	0.51	0.43, 0.58
Boys	96	121	187	0.61	0.54, 0.67	0.79	0.72, 0.87	0.97	0.97, 0.98	0.51	0.44, 0.59
Height <5th percentile	40	80	40	0.66	0.56, 0.76	0.50	0.39, 0.61	1.00	1.00, 1.00	1.00	1.00, 1.00
Height >95th percentile	144	144	320	0.60	0.55, 0.66	1.00	1.00, 1.00	0.96	0.96, 0.97	0.45	0.40, 0.51

Abbreviations: BP, blood pressure; CI, confidence interval; PPV, positive predictive value.

[a] BP tables are from reference 4.

In contrast, when we used the highest threshold in the Fourth Report BP tables, an additional 176 (3.7%) were classified as having a SBP in the 95th percentile or higher (PPV = 0.45). Table 2 shows additional data on the validity of the BP tables for identifying a single SBP measurement in the 95th percentile or higher.

Of 30,532 patients who had BP measurements taken on at least 3 separate visits, 1,458 (4.8%) were included in the analyses of hypertension status. When we used the algorithm, 35 (1.9%) had 3 or more SBPs in the 95th percentile or higher. Only 18 of these children would be classified as having hypertension using the Fourth Report BP tables (sensitivity = 0.51). Of the 4,770 children with heights higher than the 95th percentile, 4,070 (85%) had BPs recorded at 3 or more separate visits. Of these, 49 (1.2%) were classified as having hypertension when we used the algorithm, whereas an additional 54 children (1.3%) were classified as hypertensive when we used the Fourth Report BP tables (PPV = 0.48) (Table 3).

DISCUSSION

The present retrospective study demonstrates the potential for misclassification of BP status in short and tall children using thresholds available in the BP tables published in the Fourth Report. For both identifying a single elevated BP measurement and diagnosing hypertension, the BP tables had low sensitivity for children with heights less than the 5th percentile and low PPV for children with heights greater than the 95th percentile. Our results indicate that using the Fourth Report BP tables rather than exact calculations to classify hypertension status yields a small number of false positives and a very high rate of false negatives.

Table 3. Comparison Between the Standard Blood Pressure Tables[a] and Exact Calculation to Identify Hypertension[b] Among Children With Heights Less Than the 5th Percentile or Higher Than the 95th Percentile ($n = 5{,}528$), HealthPartners Medical Group, 2007–2012

Stratum	No. Concordant	No. Classified With Exact Algorithm	# Classified With BP Tables	κ	95% CI	Sensitivity	95% CI	Specificity	95% CI	PPV	95% CI
Total	67	84	121	0.64	0.57, 0.72	0.80	0.71, 0.88	0.99	0.99, 0.99	0.55	0.47, 0.64
Age 3–11 years	40	49	87	0.58	0.48, 0.68	0.82	0.71, 0.93	0.99	0.98, 0.99	0.46	0.36, 0.56
Age 12–17 years	27	35	34	0.78	0.67, 0.89	0.77	0.63, 0.91	1.00	1.00, 1.00	0.79	0.66, 0.93
Girls	28	37	63	0.55	0.43, 0.67	0.76	0.62, 0.90	0.99	0.98, 0.99	0.44	0.32, 0.57.58
Boys	39	47	58	0.74	0.64, 0.83	0.83	0.72, 0.94	0.99	0.99, 1.00	0.67	0.55, 0.790.59
Height <5th percentile	18	35	18	0.67	0.53, 0.82	0.51	0.35, 0.68	1.00	1.00, 1.00	1.00	1.00, 1.0000
Height >95th percentile	49	49	103	0.64	0.55, 0.73	1.00	1.00, 1.00	0.99	0.98, 0.99	0.48	0.38, 0.57

Abbreviations: BP, blood pressure; CI, confidence interval; PPV, positive predictive value.

[a] BP tables are from reference 4.

[b] Hypertension was defined as having a systolic blood pressure in the 95th percentile or higher on at least 3 separate primary care visits.

Despite the relatively low prevalence of hypertension reported in studies of children and adolescents that were conducted in ambulatory practices within large health care systems and included grade school children (8–10), these data have important clinical implications for the longitudinal evaluation of BP in children. We found that 17% of children and adolescents with a BP and height recorded during a primary care visit had a height less than the 5th percentile or greater than the 95th percentile, leading to the potential for misclassification of hypertension status. Because BP evaluation is part of routine care and presents a very low burden to patients, there is little harm in having a low PPV—for example, a child may undergo additional BP measurements to rule out hypertension. On the other hand, low sensitivity underestimates the true incidence of hypertension and might lead to delayed recognition of hypertension in patients, requiring additional follow-up or treatment.

We observed that 17% of our study population was at one of the extremes of height according to the Centers for Disease Control and Prevention growth charts (6). This is counterintuitive given that the expected proportion would be 10% using percentile cutoffs of less than the 5th and higher than the 95th. Our findings point to the issues related to classification of BP percentiles in a present-day population that represents a shift from the distribution of heights observed in historic populations used to create the standard Centers for Disease Control and Prevention growth charts (11).

The present study has 2 important limitations. First, some have questioned the accuracy of BP, height, and weight measurements obtained in the course of routine clinical care (12). Clinic nurses at all study sites were trained in proper BP, height, and weight measurement techniques for children and adolescents, and data review procedures were implemented to identify and exclude a relatively small number of inconsistent or clinically implausible measures, especially for height. Thus, these data, although imperfect, reflect the reality of the clinical setting and the information at hand when clinicians are faced with making decisions about care. Second, the study population of children and adolescents at the extremes is relatively small, making these estimates prone to error; thus, care should be taken when interpreting these findings.

Although we assigned the exact BP percentile calculation as the gold standard in these analyses, both the z score for height and the algorithm incorporating height z score to calculate BP percentile might be less reliable at the extremes of height. An alternative approach would be to develop BP tables or specific BP percentile algorithms for children with short or tall stature. Ultimately, longitudinal data on how blood pressure percentiles correlate with cardiovascular outcomes in these children would help inform optimal thresholds for their BP classification.

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APPENDIX

Below are formulas for the calculation of systolic blood pressure (SBP) and diastolic blood pressure (DBP) percentiles in children and adolescent aged 3–17 years using heights truncated at less than the 5th percentile or more than the 95th percentile for age and sex.

Boys

Expected truncated SBP = 102.19768 + 1.82416 × age − 10)) + 0.12776 × age − 10)^2)) + 0.00249 × age − 10)^3)) − 0.00135 × age − 10)^4)) + 2.73157 × truncated height percentile z score)) − 0.19618 × truncated height percentile z score)^2) − 0.04659 × truncated height percentile z score)^3) + 0.00947 × truncated height percentile z score)^4)

Truncated SBP z score = systolic BP − Expected SBP percentile)/10.7128)

SBP truncated percentile = prob SBP z score) × 100

Expected truncated DBP = 61.01217 + 0.68314 × age − 10)) − 0.09835 × age − 10)^2)) + 0.01711 × age − 10)^3)) + 0.00045 × age − 10)^4)) + 1.46993 × truncated height percentile z score)) − 0.07849 × truncated height percentile z score)^2) − 0.03144 × truncated height percentile z score)^3) + 0.00967 × truncated height percentile z score)^4)

Truncated DBP z score = diastolic BP − Expected DBP)/11.6032)

DBP truncated percentile = prob DBP z score) × 100

Girls

Expected truncated SBP = 102.01027 + 1.94397 × age − 10)) + 0.00598 × age − 10)^2)) − 0.00789 × age − 10)^3)) − 0.00059 × age − 10)^4)) + 2.03526 × truncated height percentile z score)) + 0.02534 × truncated height percentile z score)^2) − 0.01884 × truncated height percentile z score)^3) + 0.00121 × truncated height percentile z score)^4)

Truncated SBP z score = systolic − Expected SBP)/10.4855)

SBP truncated percentile = prob SBP z score) × 100

Expected truncated DBP = 60.50510 + 1.01301 × age − 10)) + 0.01157 × age − 10)^2)) + 0.00424 × age − 10)^3)) − 0.00137 × age−10)^4)) + 1.16641 × truncated height percentile z score)) + 0.12795 × truncated height percentile z score)^2) − 0.03869 × truncated height percentile z score)^3) − 0.00079 × truncated height percentile z score)^4)

Truncated DBP z score = diastolic − Expected DBP)/10.9573)

DBP truncated percentile = prob DBP z score) × 100