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Oscillometric Blood Pressure Standards for Children

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Abstract. We previously reported blood pressure (BP) readings obtained by the Dinamap (DIN) (Model 8100) were 10 mmHg higher than those obtained by auscultatory methods and thus were not interchangeable. DIN BP data on 7208 schoolchildren ages 5 to 17 were analyzed to generate normative DIN BP standards and to examine the rational for presenting BP standards according to age and height percentiles. Three BP measurements were taken in the sitting position using a BP cuff width 40% to 50% of the circumference of the arm. Boys' systolic pressures (SP) were significantly ($p < 0.05$) greater (up to 11 mmHg) than those of the girls in subjects age 13 to 17 years. SP levels were most closely correlated with weight ($r = 0.595$), followed by height ($r = 0.560$) and age ($r = 0.518$). When BP levels were adjusted for age and weight, the correlation coefficient of DIN SP with height was negligible ($r = 0.026$ for boys; $r = 0.085$ for girls), whereas when adjusted for age and height, the correlation of SP with weight remained high ($r = 0.303$ for boys; $r = 0.216$ for girls), indicating that height is not an important independent predictor of BP levels. In conclusion, Dinamap-specific BP standards presented in this report are the only standards that have been generated according to the current BP guidelines recommended by national committees. We found no rational for presenting BP standards according to age and height percentiles.

Key words: Blood pressure — Children — Oscillometric device — Normal standards — Dinamap monitor

Since the accuracy of an oscillometric device in reflecting direct arterial pressure has been reported to be high in infants and children [10, 26], as well as adults [2], the Dinamap Monitor has become widely used in pediatric patient care. Recently, we reported that systolic blood pressure readings obtained by Dinamap Model 8100 averaged approximately 10 mmHg higher than those obtained by the auscultatory method so that blood pressure (BP) readings by the two methods were not interchangeable [12]. Despite that report, many physicians and health care providers continue to use auscultatory BP standards in assessing Dinamap measurements because such Dinamap BP standards are not available. This may create confusion in the diagnosis of hypertension in the pediatric age group, possibly making an erroneous diagnosis of hypertension in a normotensive child. Analyzing existing Dinamap BP data would provide the needed BP standards. We analyzed Dinamap BP data on 7028 schoolchildren. These data were obtained between 1992 and 1997 during the San Antonio Children's Blood Pressure Study. In that study, we found no consistent differences in BP levels among African American, Mexican American, and non-Hispanic white children 5 to 17 years of age [13]. Analysis of this aspect will not be repeated here.

There are two different ways of presenting BP standards in children. One popular method presents BP percentile values in a graphic form according to age, such as those presented by the National Institute of Health (NIH) Task Force-1977 [17] and Task Force-1988 [6]. The other method, recommended by the Working Group of the National High Blood Pressure Education Program (NHBPEP) [20], presents data according to age and height percentiles in a tabular form without showing the mean values. The latter method is impractical and appears illogical. A number of large epidemiologic studies indicate that weight is more closely correlated with BP levels [7-9, 16, 22, 23] than height. We reported that auscultatory BP levels are more closely correlated with weight than

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with height [13] and we suggested that if a second variable other than age is to be considered, weight would be a better choice than height. An examination of the correlation of oscillometric BP with weight and height may provide additional information regarding this issue.

Therefore, the primary purpose of this study was to generate Dinamap-specific normative BP standards by analyzing existing Dinamap BP data obtained during the San Antonio Children's Blood Pressure Study from more than 7000 schoolchildren. The secondary purpose of the study was to examine the rationale for presenting normative oscillometric BP levels according to age and height percentiles.

Methods

The institutionally approved San Antonio Children's Blood Pressure Study was conducted between 1992 and 1997. Detailed methods have been described in two previous publications [12, 13]. One report noted the presence of a major difference in BP levels obtained by the auscultatory and Dinamap methods [12]. The other described the absence of consistent ethnic differences in either ausculatatory or Dinamap BP measurements [13]. Next, the methodology pertinent to the purposes of this report is described.

Volunteer schoolchildren enrolled in kindergarten through 12th grade in the San Antonio, Texas, area participated in the study. In the study, measurements of weight, height, and arm circumference were obtained (in that order) before BP measurements were taken. One of the goals of the study was to compare BP readings by the auscultatory and Dinamap methods. In order to eliminate the influence of the order of BP measurement by different devices [26], each child was randomly assigned to either the auscultatory method first followed by the Dinamap method (A-rotation) or the reverse order (D-rotation). The student was seated at the assigned station for 5-10 minutes and three measurements of BP were taken by one method and then by the other method. Blood pressure cuffs were selected based on the circumference of the arm, with the width of the cuff 40–50% of the circumference of the right arm, as currently recommended by the American Heart Association (AHA) Special Task Force [4] and the Working Group of the NHBPEP [20].

Auscultatory BP measurement was performed using a Baumanometer mercury gravity sphygmomanometer (W.A. Bauman Co., Copiague, NY, USA) according to the methods recommended by the AHA Task Force [4]. Only those research nurses who successfully completed the 6-hour instructor's course for blood pressure determination offered by the AHA Texas affiliate [1] were selected to measure asucultatory BP. Dinamap Monitor Model 8100 (Critikon, Inc., Tampa, FL, USA) was used as the oscillometric device for this study. Observers who operated the oscillometric device were trained in the use of the device through familiarization with the manual and hands-on practice.

Blood pressure measurements were made at least 1 hour after meals [14, 15] and at three different times of the day (midmorning, late morning, or afternoon) in an air-conditioned room, usually the school library. Days with physical education class were avoided [14]. BP cuffs manufactured by Critikon, which were easily adaptable for the Baumanometer, were used for both the auscultatory and the Dinamap methods so that the same-sized BP cuffs were used on each child for both methods.

The average of the triplicate readings was used for statistical analyses using SAS Software (SAS Institute, Carey, NC, USA). Dinamap BP data from 7208 children were statistically analyzed. The mean and standard deviation were computed for males and females for a possible gender difference in BP levels by analysis of variance followed by the Bonferroni test for each age group. Statistical significance was accepted at the 5% level. Correlation coefficients were computed between BP levels and anthropometric variables. Differences in BP readings by the two methods were computed by subtracting the average of the triplicate auscultatory readings from that of the DIN method as reported previously [12]. Dinamap BP percentile values were computed for males and females by the method used by the NIH Task Force-87 in fitting BP percentiles [6].

In developing the normative Dinamap BP standards, we combined data from all ethnic groups because there was no consistent ethnic difference in systolic or diastolic pressures by either the auscultatory or the Dinamap method, as has been reported previously [13].

Results

Among the participants, 58.5% were Mexican American, 28.3% were non-Hispanic white, and 13.2% were African American. There were 3356 boys and 3852 girls in the study population. Dinamap BP readings taken at different times of the day (i.e., midmorning, late morning, and afternoon) showed no statistical difference ($p > 0.05$) for any age group. Comparison of the average of three Dinamap BP (systolic, diastolic, and mean) readings between children in the A-rotation (those who had their BP measurement done by the auscultatory method first and then by the Dinamap Monitor) and those in the D-rotation (those who had their BP taken in the reverse order as the A-rotation group) showed no systematic differences ($p > 0.05$), as has been reported earlier [12, 13]. Therefore, the Dinamap BP readings for A-rotation and D-rotation groups as well as those taken at different times of the day were combined for statistical analyses. The first BP readings averaged 1 or 2 mmHg higher than the average of the three readings and were 1.5-3 mmHg higher than the average of the second and third readings ($p < 0.05$). The first diastolic pressure reading averaged less than 1.5 mmHg higher than the average of the triplicate readings or of the average of the second and third readings ($p < 0.05$).

Systolic and diastolic pressures as a function of age are shown in Fig. 1 for females and in Fig. 2 for males. Although there was no consistent difference in BP levels of clinical importance among the three ethnic groups [13], a gender difference in systolic pressure began to appear at age 13 years for all ethnic groups, with boys showing significantly higher systolic pressures than girls ($p < 0.05$). The difference

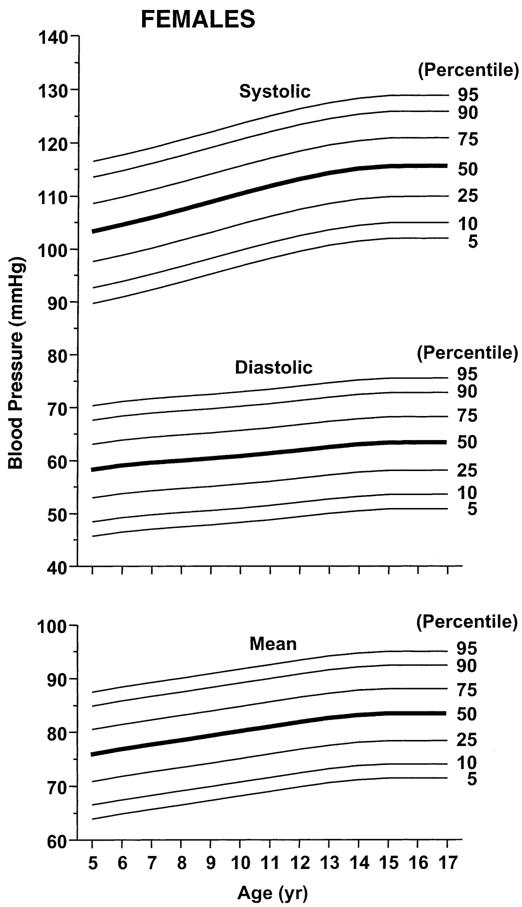

Fig. 1. Systolic, diastolic, and mean blood pressures as a function of age for females.

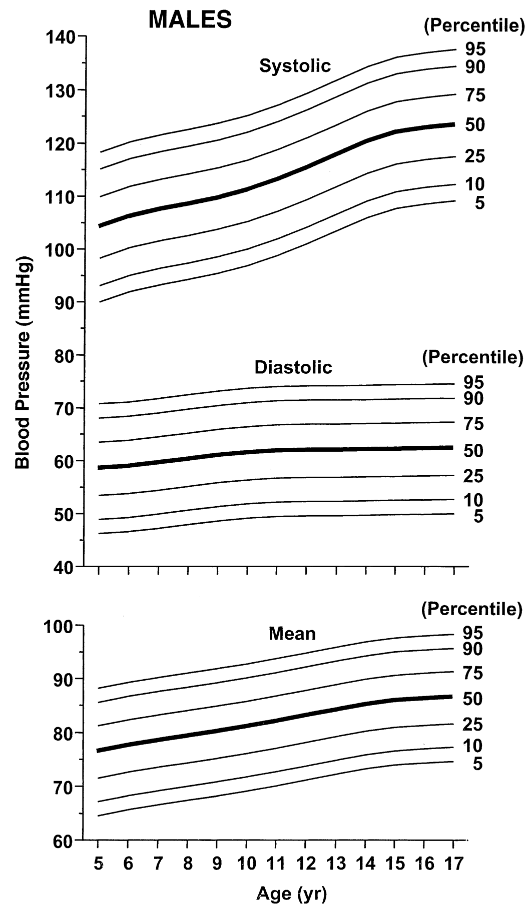

Fig. 2. Systolic, diastolic, and mean blood pressures as a function of age for males.

was as large as 11 mmHg. Therefore, normative standards are presented according to gender. For Dinamap diastolic pressures, no consistent gender-related difference was found (Figs. 1 and 2).

Dinamap systolic pressure levels correlated most strongly with weight ($r = 0.639$ for boys; $r = 0.500$ for girls) and less well with height ($r = 0.594$ for boys; $r = 0.477$ for girls), followed by age ($r = 0.559$ for boys; $r = 0.418$ for girls) and body mass index ($r = 0.532$ for boys; $r = 0.419$ for girls). Dinamap diastolic pressure correlated poorly with all anthropometric variables, the closest correlation being with weight but with a correlation coefficient of only 0.19. Dinamap systolic pressure correlations were closer with the combination of age and weight than with the combination of age and height. When systolic pressure was adjusted for age and weight, the correlation coefficient for systolic pressure with height was very small ($r = 0.026$ for boys; $r = 0.085$ for girls), whereas when it was adjusted for age and height, the correlation of systolic BP with weight remained high ($r = 0.303$ for boys; $r = 0.216$ for girls).

Discussion

We developed Dinamap-specific BP percentile values by analyzing existing Dinamap BP data because normative data are not available for this method and the values differ between the auscultatory and the Dinamap methods [12]. The Dinamap systolic pressures were 8-12 mmHg higher than the auscultatory pressures and the Dinamap diastolic pressures were 4 or 5 mmHg higher than auscultatory K5 diastolic pressures [12]. Thus, BP readings obtained by the auscultatory and Dinamap methods are not interchangeable. Use of the auscultatory BP standards to evaluate children's Dinamap BP readings may lead to an incorrect assessment of the BP readings. Although one may use a correction factor based on the previous findings, Dinamap-pecific normative standards are simpler and provide a more accurate assessment of a child's BP status.

Blood pressure levels are known to be correlated with body size (weight, height, or body mass index) such that age alone is inadequate to gauge whether a child is normotensive or hypertensive [8, 16, 23, 24]. According to the recommendation by the NIH Task Force-1977 [17] and Task Force-1987 [6], before making the diagnosis of pediatric hypertension when BP values exceed the 90th percentile, one considers whether the child's weight or height are also at a high percentile. In this case, the high BP may be due to body size and not true hypertension [6]. Weight control would be the preferred therapeutic approach [6]. In this report, we use this approach [6, 17] and present the values in percentile curves according to age.

The results of this study suggest no rationale for presenting BP data as a function of age and height percentile as presented by the working group of NHBPEP [20]. In this study, weight was more closely correlated with systolic pressures than height. The same was reported in our earlier study of asuscultatory BP levels [13] and in a number of other reports using the auscultatory method [7–9, 16, 21, 23]. In addition, we found that when age and weight were used in the partial correlation analysis, the effect of height on BP levels virtually disappeared (Table 1). However, when adjusted for age and height, the contribution of weight on BP levels remained high. Gain and loss of weight correlate well with an increase and decrease in BP levels in children and adolescents [18]. Incorporating a variable other than age (such as weight or height) in presenting BP standards is cumbersome and impractical. However, if one decides to use a measure of body size, weight is a better choice than height. Pediatricians are familiar with a graphic form of data presentation, such as weight and height growth charts, and the NIH Task Force's BP standards [6], which allow assessment of a child's BP value in comparison to the general population. The tabular form presented by the working group [20] does not include the mean (or the 50th percentile) and thus is not useful in checking the position of the child's BP levels or in the tracking of BP levels in children. Quantification of the degree to which children's blood pressure tracks is important for early diagnosis and intervention in high BP [25].

Another point regarding the working group's normative BP standards is that although the working group recommended averaging two or more BP readings using BP cuff width of 40-50% of the circumference of the arm, its normative standards were not all derived by that methodology but were the results of a single (or the first) measurement of BP using a BP cuff selection based on the length of the arm. In large children, especially, BP readings may be in error if the BP cuff is too small relative to arm circumference. The normative data presented here were derived from the average of three readings using the circumference-based BP cuff selection method. Averaging of multiple BP readings is closer to the basal BP levels [23], and Gillman and Cook [5] recommended averaging three readings per visit. If one decides to take only one reading, it should be kept in mind that the first (or single) readings are usually higher than the average of multiple readings [5, 23, 26]. If the initial BP is at a high percentile level or in the hypertensive range, the average of three readings should be obtained and compared with the blood pressure standards. If the child's BP level is at the 90th percentile or higher and the child's weight is also at a high percentile level, the high value of BP readings may be related to the large body size, as suggested by the NIH task force [6]. Of course, the diagnosis of hypertension should not be made on a single visit. Abnormally high BP readings on at least three different visits are recommended for the diagnosis of hypertension [5, 6, 20].

There has been a significant increase in the prevalence of children's obesity in recent years [19], and obesity is associated with increased BP levels in children [3]. A question may be raised as to how the high prevalence of obesity and the inherent rise in children's BP would have affected the normal BP standards in this report. Blood pressure and body mass index (BMI) data of the study population [11, 13] have non-Gaussian distributions that were somewhat skewed toward higher levels of BP and profoundly skewed toward higher values of BMI. Examination of the entire BMI distribution in the series of the National Studies showed that the heaviest children were markedly heavier in a recent study than in older studies, but the rest of the distribution of BMI showed little change [19]. The formula used by the NIH Task Force-1987 [6] and by us in this report forces a normal distribution around the mean value (defined by the spline curve estimates and the residual error) to symmetrically reflect the lower and upper percentile values. Therefore, even though the data were obtained from a population with a considerable prevalence of obesity [11], these normative standards will identify obesity-influenced high BP levels in overweight children as abnormal levels of BP.

In conclusion, normative Dinamap BP standards presented in this report were obtained by averaging three BP readings using circumference-based BP cuffs as recommended by national committees on children's BP measurement [4, 20]. When BP is obtained by the Dinamap Monitor 8100, one should use Dinamap-specific normative BP standards rather than the normative tables produced by and for the auscultatory method. Not doing so may result in an erroneous evaluation of BP in a normotensive child. We believe that normative BP standards presented according to age in a graphic form showing percentile curves are more useful and logical.

Table 1. Oscillometric blood pressure percentile values for boys and girls according to age (mmHg)

Age (years)	5th %	10th %	25th %	Mean	75th %	90th %	95th %
Boys							
Systolic pressure							
5	90	93	98	104	110	115	118
6	92	95	100	106	112	117	120
7	93	96	102	107	113	118	121
8	94	97	103	108	114	119	123
9	95	99	104	110	115	121	124
10	97	100	105	111	117	122	125
11	99	102	107	113	119	124	127
12	101	104	109	115	121	126	129
13	104	107	112	118	123	129	132
14	106	109	114	120	126	131	134
15	108	111	116	122	128	133	136
16	109	112	117	123	128	134	137
17	109	112	117	123	129	134	137
Diastolic pressure							
5	46	49	53	58	63	68	71
6	47	49	54	59	64	68	71
7	47	50	54	59	64	69	72
8	48	51	55	60	65	70	72
9	49	51	56	61	66	70	73
10	49	52	56	61	66	71	74
11	49	52	57	62	67	71	74
12	50	52	57	62	67	71	74
13	50	52	57	62	67	71	74
14	50	52	57	62	67	72	74
15	50	52	57	62	67	72	74
16	50	53	57	62	67	72	74
17	50	53	57	62	67	72	75
Mean pressure							
5	65	67	72	76	81	86	88
6	66	68	73	77	82	87	89
7	67	69	74	78	83	88	90
8	67	70	74	79	84	88	91
9	68	71	75	80	85	89	92
10	69	72	76	81	86	90	93
11	70	73	77	82	87	91	94
12	71	74	78	83	88	92	95
13	72	75	79	84	89	93	96
14	73	76	80	85	90	94	97
15	74	77	81	86	91	95	98
16	74	77	81	86	91	95	98
17	75	77	82	86	91	96	98
Girls							
Systolic pressure							
5	90	93	98	103	109	114	117
6	91	94	99	104	110	115	118
7	92	95	100	106	111	116	119
8	94	97	102	107	113	118	121
9	95	98	103	109	114	119	122
10	97	100	105	110	116	121	124
11	98	101	106	112	117	122	125
12	100	103	107	113	118	123	126
13	101	104	109	114	120	125	128
14	102	104	109	115	120	125	128
15	102	105	110	115	121	126	129
16	102	105	110	115	121	126	129
17	102	105	110	115	121	126	129

Table 1. Continued

Age (years)	5th %	10th %	25th %	Mean	75th %	90th %	95th %
Diastolic pressure							
5	46	48	53	58	63	68	70
6	46	49	54	59	64	68	71
7	47	50	54	59	64	69	72
8	47	50	55	60	65	69	72
9	48	51	55	60	65	70	72
10	48	51	56	61	66	70	73
11	49	52	56	61	66	71	73
12	49	52	57	62	67	71	74
13	50	53	57	62	67	72	75
14	51	53	58	63	68	72	75
15	51	54	58	63	68	73	76
16	51	54	58	63	68	73	76
17	51	54	58	63	68	73	76
Mean pressure							
5	64	67	71	76	81	85	87
6	65	67	72	77	81	86	88
7	66	68	73	77	82	87	89
8	66	69	73	78	83	87	90
9	67	70	74	79	84	88	91
10	68	71	75	80	85	89	92
11	69	72	76	81	86	90	93
12	70	72	77	82	86	91	93
13	71	73	78	82	87	92	94
14	71	74	78	83	88	92	95
15	71	74	78	83	88	92	95
16	71	74	78	83	88	92	95
17	71	74	78	83	88	92	95

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