Blood Pressure Recording in Children

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Long, M., Dunlop, J. R., and Holland, W. W. (1971). *Archives of Disease in Childhood*, **46**, 636. **Blood pressure recording in children.** Blood pressure levels for 148 children aged 0–14 years were recorded. Two different methods of measurement (the standard sphygmomanometer and the random-zero machine) and two cuffs of varying size were used on each child. Measurements of arm size and pulse rate were taken, and an assessment was made of the emotional state of each child: no association was found between these factors and the recorded measurement of blood pressure. The experiment does however show that: (1) the effect of cuff size can be minimized by using the largest cuff that will fit the child, and then applying a standard correction to the measurement taken; and (2) the random-zero machine is a preferable method of measurement as it reduces observer bias, though measurements taken with a standard and a random-zero machine are not directly comparable.

The many factors that appear to affect the validity of indirect blood pressure readings in both children and adults have now been the subject of investigation for more than 30 years. In studies of direct and indirect readings of blood pressure in infants and older children, Woodbury, Robinow, and Hamilton (1938) and Robinow *et al.* (1939) showed that, when arbitrarily selected cuffs were used, the accuracy of indirect readings was greatly affected by the relation between arm size (as determined by arm circumference) and the size of the blood pressure cuff. They concluded that the smaller the arm, the narrower the cuff should be, and that, for the newborn, cuffs wider than 2.5 cm would produce artificially low readings. In a study of 51 adults, Ragan and Bordley (1941) attributed differences between direct and indirect blood pressure measurements to the influence of arm circumference measurements. It should, however, be noted that some of their subjects were patients with aortic incompetence. The authors also compared the relative accuracy of the standard American 13 cm cuff with the 20 cm cuff, finding that the wider cuff gave more 'accurate' readings where the arm circumference was large, though its use in 'average' subjects produced artificially low readings.

In a more recent study Holland and Humerfelt (1964) compared direct and indirect readings in 47 adults, using a method of recording indirect blood pressure free from observer bias (Holland, 1963) and a standard 12 × 24 cm cuff. In an assessment of the influence of arm size, skinfold thickness, and weight on the relation between differences in direct and indirect readings, differences were found to be greater as the direct level of blood pressure increased. There was a small correlation between arm circumference and level of indirect arterial pressure, but, as this was largely contributed by the effect of weight, the authors suggested that in adults no allowance need be made in adjustments of levels of blood pressure. This conclusion is supported by a study of indirect blood pressure measurements in about 5000 men aged 15–69 (Khosla and Lowe, 1965), in which readings were found to be affected by the relative weight of the individual, but not by the arm circumference *per se*.

Karvonen, Telivuo, and Järvinen (1964) drew attention to another factor that could influence blood pressure readings. In a comparison of direct and indirect readings in 53 subjects, they found that too short a cuff bladder may, like too narrow a cuff, produce artificially high readings. Once this was taken into account, arm circumference had no influence on levels of blood pressure. Similarly, King (1967) and Simpson *et al.* (1965) found that low indirect pressure readings resulted from the use of cuffs that were wider and longer

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than standard. In a study of the effect of simulated obesity as determined by arm circumference measurement, King (1967) found that too short a blood pressure bladder produced artificially high readings, but concluded that, once the cuff had encircled the arm, the effect of the cuff length on the readings was minimal. He stressed the importance of these findings for paediatric studies.

In studies of infants, Lang and Hilber (1969) used an electric method of recording indirect blood pressure readings similar to electric impedance plethysmography to compare readings obtained by cuffs 2, 4, and 6 cm wide. He concluded that the 4 cm cuff produced the most accurate readings and the 6 cm cuff was often too large for the subject. Unfortunately, most paediatric studies of blood pressure recordings have so far been concerned only with techniques of measurement, of which the most commonly used are palpation (Holland and Young, 1956), electrical impedance plethysmography (Lang and Hilber, 1969), and the flush method. Few, if any, paediatric studies have systematically considered all factors that could contribute to variation in blood pressure readings, though Rose, Holland, and Crowley (1964) have summarized possible sources of error in adults, and these are, of course, equally applicable to children. In view of the many sources of possible error in recording blood pressure in children, readings may often have minimal clinical value, and many may even be misleading. This investigation, therefore, attempts to find a method of measuring blood pressure in children, which will enable valid comparisons to be made between children independent of their age, size, or the cuff size used.

Material and Methods

148 children from paediatric wards and outpatient clinics were examined by 5 observers over a period of 2 months. On each patient, blood pressure measurements were taken using a standard and a random-zero sphygmomanometer (Wright and Dore, 1970), a modification of the Garrow Zero Muddler, which is designed to reduce observer bias (Garrow, 1963). The observers were carefully trained in the use of both machines, and the observer technique was standardized by listening to blood pressure recordings (Rose, 1965). Systolic pressure, diastolic I (Korotkow 4th phase) and diastolic II pressure (Korotkow 5th phase) were recorded on each occasion.

Each child was measured with two cuffs of differing size. Five standard cuffs, manufactured by Accoson but with extended velcro fastenings, were used: cuff 1—4 in. $\times$ 1 in. (10 $\times$ 2.54 cm); cuff 2—4 in. $\times$ 2 in. (10 $\times$ 5.08 cm); cuff 3—6 in. $\times$ 3 in. (15.24 $\times$ 7.62 cm); cuff 4—7½ in. $\times$ 4 in. (19.05 $\times$ 10.16 cm);

and cuff 5—9 in. $\times$ 5 in. (22.86 $\times$ 12.70 cm). The children were divided into four age groups, 0–1, 1–4, 5–9, and 10–14 years. In the three youngest age groups two cuffs were used for each group; in the oldest age group three cuffs were used, as there was greater variation in the size of the older children (Table I).

TABLE I

Number of Children Tested in Each Age Group and Cuff Sizes Used

Age (yr)	Cuff Sizes Used	No. of Children Measured
0–1	1,2	16
1–4	2,3	32
5–9	3,4	40
10–14	3,4	20
10–14	3,5	20
10–14	4,5	20
	Total	148

The following arm measurements were taken on each child: (1) upper arm length (in cm) measured from the acromion process to the olecranon using a flexible steel tape; (2) arm circumference (in cm) measured at the mid-point between the acromion and the olecranon; and (3) skinfold thickness over the triceps muscles, at the same level as arm circumference, using the Harpenden skinfold thickness caliper (Edwards *et al.*, 1955).

All readings were taken on the left arm with the child seated. The pulse rate and emotional state of the child were also recorded during the examination. Two observers were present, one recording results while the other either entertained or held the child. The order in which the cuffs and methods of recording were used was randomly allocated. If a child did not co-operate for any one of the readings, the results for that child were not included in the analyses comparing cuff sizes and recorded measurements (Tables II, III, and VI).

Results

Influence of cuff size. Within each age group the level of blood pressure recorded was higher when the smaller cuff was used. This was found true for both systolic and diastolic pressures. Using cuffs 1 or 2, it appeared that levels of blood pressure were higher in children aged less than 1 year than in children aged 1–4 years (Table II).

For each group of children on which the five different combinations of cuffs were used, and for each of the three phases of blood pressure, the average difference between the readings with the smaller and larger cuff was regressed on arm length, arm circumference, and skinfold thickness, separately and in combination. Surprisingly, not even one of these 60 regressions was significant at the 5% level. As no association could be found

TABLE II
Mean Blood Pressure According to Cuff Size and Phase

Age Group (yr)	Cuff Size Used	Systolic Pressure (mmHg)		Diastolic I Pressure (mmHg)		Diastolic II Pressure (mmHg)		No. of Children*
		Smaller Cuff	Larger Cuff	Smaller Cuff	Larger Cuff	Smaller Cuff	Larger Cuff	
0-1	1,2	134	114	91	73	84	68	15
1-4	2,3	120	101	81	64	72	56	30
5-9	3,4	104	100	69	65	61	58	38
10-14	3,4	111	106	76	71	70	64	20
10-14	4,5	113	108	77	73	70	68	20
10-14	3,5	110	100	77	71	71	63	20

*5 children who cried or struggled have been excluded from this analysis.

TABLE III
Mean Levels of Blood Pressure According to Method of Measurement and Cuff Size

Blood Pressure	Machine	Cuff					Weighted Means
		1	2	3	4	5	
Systolic	Zero-Muddler	131	119	104	103	103	107.3
	Normal	136	117	107	106	104	109.5
Diastolic I	Zero-Muddler	89	79	69	67	70	71.5
	Normal	92	78	72	72	73	74.0
Diastolic II	Zero-Muddler	82	72	62	60	64	64.1
	Normal	84	70	65	65	68	66.8
*No. of children		15	45	108	78	40	

*5 children who cried or struggled have been excluded from the analysis.

TABLE IV
Frequency of Each Terminal Digit According to Fieldworker and Machine

Field-worker	Terminal Digit					Total	χ^2_4
	0	2	4	6	8		
<i>Standard Method</i>							
A	97	27	28	26	38	216	85.90†
B	38	28	42	62	36	216	10.67*
C	35	17	15	18	23	108	12.00†
D	49	11	11	8	29	108	56.26†
E	96	19	20	49	30	214	96.22†
<i>Zero Muddler</i>							
A	44	44	37	47	44	216	1.26
B	41	41	41	52	41	216	2.24
C	14	21	27	22	24	108	4.31
D	34	10	18	21	25	108	14.50†
E	59	33	39	47	36	214	10.20*

*Probabilities = 5%—2.5%

†Probabilities = 1%—0.5%

‡Probabilities = 0%—0.1%

between the variables and the different measurements, with different cuffs, differences in arm measurements were ignored in subsequent analyses.

Influence of emotional state and pulse rate.

It was found impossible to assess the influence of the emotional state of the child on the blood pressure recorded, as most (80%) of the children were placid at the time of measurement. An analysis of covariance was carried out on the readings of 56 children measured with cuffs 3 and 4, with the children, cuff, and machine as factors, and the pulse rate as a covariate. However, the regression coefficient was not significant in any of the three phases, indicating that there was no correlation between pulse rate and level of blood pressure.

Methods of recording blood pressure.

Theoretically the two blood pressure recording machines should give the same readings. We found that, however, in almost all cases levels of pressure were lower with the random zero machine (Table III). The difference between the two machines is about 2 mmHg. This was also found by Evans and Prior (1970).

This variation is difficult to explain. It cannot be due to the order of measurement, nor to differences in perception of end point. It is possibly attributable to small differences in the machines

used, or to the fact that, when the level of mercury was between two marks, observers were instructed to read to the nearest 2 mm below. When the Garrow machine was used, this procedure was, of course, followed twice, once when taking the reading and once when subtracting the 'zero correction'. This may account for at least 1 mm of the difference.

The Garrow machine is designed to reduce observer variability. One measure of this is the frequency of recording terminal digits (digit preference). All five observers showed a marked digit preference when using the normal machine, but with the Garrow machine terminal digit preference was eliminated in three observers and noticeably reduced in the other two (Table IV).

Discussion

This investigation clearly shows the difficulties involved in choosing the right cuff size for the measurement of blood pressure in children. Factors such as upper arm length, arm circumference, and skinfold thickness appeared to have little influence on the level of blood pressure recorded, a finding that replicates those of similar investigations on adults (Holland and Humerfelt, 1964). In addition, pulse rate did not appear to have an effect on the recorded level.

However, differences were found in the same child when cuffs of differing size were used, smaller cuffs giving consistently higher readings. One possible explanation for this is that the excess pressure generated by a small cuff is dissipated into the surrounding flesh; this effect is of course lessened as wider cuffs are used. If, therefore, one assumes that every reading with a small cuff has an intrinsic bias, it may be possible to estimate the extent of this bias, and thus to obtain comparable readings in the same child when using a different cuff. The extent of this bias may be calculated

by regressing the blood pressure readings recorded by two different cuffs and the size of cuff within each age group (see Appendix for method). Table V gives the results of such an analysis and shows the

TABLE V
Correction for Smaller Cuffs to Obtain Readings Comparable to Those Given Using a Large Cuff

Cuff Sizes	Cuff	Systolic	Diastolic I	Diastolic II
4 in. × 1 in.	1	44.8	39.8	36.7
4 in. × 2 in.	2	27.5	23.4	23.1
6 in. × 3 in.	3	9.7	6.9	7.2
7½ in. × 4 in.	4	5.8	3.0	2.5
9 in. × 5 in.	5	0.0	0.0	0.0

Example (1) Systolic blood pressure of small child = 130 mmHg.
Cuff 1 used.
Corrected systolic blood pressure = $130 - 44.8 = 85.2$ mmHg.
(2) Diastolic blood pressure in toddler = 70 mmHg.
Cuff 3 used.
Corrected diastolic blood pressure = $70 - 6.9 = 63.1$ mmHg.
(3) Diastolic 2 blood pressure in teenager = 70 mmHg.
Cuff 4 used.
Corrected diastolic 2 pressure = $70 - 2.5 = 67.5$ mmHg.

corrections which need to be applied to readings obtained by a small cuff in order to obtain readings comparable to those given using a large cuff. The assumption underlying the use of this technique is that a large cuff, i.e. cuff 5, has no bias, and it will be seen that the correction necessary when the smallest cuff is used is considerable, but is progressively reduced with increase in the size of cuff.

If one then applies these correction factors to the mean blood pressure readings for each age group, levels recorded by two cuffs of different size are very similar; one also finds a rise in blood pressure readings with age (Table VI). These findings would be expected. We therefore suggest that

TABLE VI
Adjusted Mean Blood Pressure According to Cuff Size

Age Group (yr)	Cuff Size Used	Systolic Pressure (mmHg)		Diastolic I Pressure (mmHg)		Diastolic II Pressure (mmHg)		No. of Children*
		Smaller Cuff	Larger Cuff	Smaller Cuff	Larger Cuff	Smaller Cuff	Larger Cuff	
0-1	1,2	89	86	51	50	47	45	15
1-4	2,3	92	91	58	57	49	49	30
5-9	3,4	94	94	62	62	54	55	38
10-14	3,4	101	100	69	68	63	61	20
10-14	4,5	107	108	74	73	67	68	20
10-14	3,5	100	100	70	71	64	63	20

*5 children who cried or struggled have been excluded from the analysis.

blood pressure in children should be measured by using the largest cuff that will comfortably encircle the arm, then applying the appropriate correction factor as indicated. This will enable valid comparisons to be made for the same child and with other children. It is recognized that we are assuming that indirect blood pressure measured with a cuff is a true reflection of the direct measurement. Other studies, e.g. Holland and Humerfelt (1964), have shown that though the absolute levels of pressure recorded by indirect and direct methods of measurement differ there is a high degree of correlation between them ($n = 0.95$ for systolic pressure). Furthermore in clinical practice one is interested not so much in an absolute as a relative level. It is necessary to know whether blood pressure has changed in a child over time, and the relative size of this change rather than the absolute values at any one point in time. Similarly it is important to know whether the level of blood pressure in one child differs from that of another. The 'true' levels are not as important as long as the distribution of these levels of indirect pressure in children are known. This method enables corrections to be made to allow comparisons between children of different sizes and in the same child at different ages.

The advantages of the random-zero machine over the standard sphygmomanometer are seen in the reduction of terminal digit preference. It is, however, also seen that there are differences in the mean levels of blood pressure recorded by the standard sphygmomanometer and the random-zero machine. Again, therefore, appropriate corrections should be applied when making comparisons between measurements recorded by the two types of machine.

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Appendix

By the method of maximum likelihood, the following model was fitted to the readings of systolic blood pressure (y_{ij}):

$$y_{ij} = \mu y + C_i + M_j + I_{ij} + \theta_1 P_1(z) + \theta_2 P_2(z) + \theta_3 P_3(z) + \theta_4 P_4(z) + e_{ij}$$

where y represents the systolic value,

C_i ($i = 1, 2, 3 \dots 144$) represents the child effect,

M_j ($j = 1, 2$) represents the machine effect,

I_{ij} represents the interaction between child and machine,

z ($z = 1, 2, 3, 4, 5$) is the cuff number,

θ_i ($i = 1, 2, 3, 4$) are the coefficients corresponding to the orthogonal polynomials

$P(z)$ and e_{ij} represent the random variation, assumed normally distributed with zero mean.

It should be noted (see page 638) that the numbers of the cuffs are proportional to their widths.

Having estimated the θ_i and A_x , where

$$A_x = \sum \hat{\theta}_i P_i(x) \quad (x = 1, 2, 3, 4, 5)$$

the adjustment relative to cuff 5 for the first four cuffs was determined by subtracting A_5 from A_i ($i = 1, 2, 3, 4$).

The analysis was repeated for the diastolic readings.

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