Random-Zero Sphygmomanometer, Rose's Tape, and the Accuracy of the Blood Pressure Measurements in Children¹

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ABSTRACT. In the Cardiovascular Risk in Young Finns project, blood pressure (BP) was measured in 3549 randomly selected children aged 6–18 y in 1980, and 2887 and 2500 of the same individuals in 1983 and 1986, respectively. An ordinary mercury sphygmomanometer (OMS) was used in the first two surveys and a random-zero sphygmomanometer (RZS) in the third survey. Systolic and diastolic BP were lower when measured with an RZS than with an OMS and the shape of the age-related BP curve obtained with an RZS was significantly different from that obtained with an OMS, because low BP values were apparently measured more accurately with the former. Use of the RZS did not affect the distribution of the BP values. Rose's tape readings were used to evaluate the effect of training and to control the accuracy of the BP measurements. According to Rose's tape readings, Korotkoff's 4th phase BP was more difficult to measure accurately than 5th phase ($p = 0.002$). The mean values for the differences between the correct and actual BP readings on the Rose's tape were -1.2 mm Hg (SD 2.1) for systolic BP, 8.3 mm Hg (SD 13.6) for diastolic Korotkoff's 4th phase BP, and 1.2 mm Hg (SD 7.0) for diastolic Korotkoff's 5th phase BP, with a negative value indicating that the BP phase was measured lower than the correct value. Terminal digit preference was present in each survey to such an extent that it could have hampered the reaching of reliable conclusions from the data obtained with an OMS. The bias caused by terminal digit preference was obviated by the RZS. Our results support the use of an RZS in BP surveys in children, because accurate measures for low BP are best achieved by RZS and because it is the only means of eliminating a major source of observer bias, terminal digit preference. Rose's tape is useful in evaluating the accuracy of BP measurements and in training. (*Pediatr Res* 32: 243–247, 1992)

Abbreviations

BP, blood pressure
 K1, Korotkoff's 1st phase
 K4, Korotkoff's 4th phase
 K5, Korotkoff's 5th phase
 OMS, ordinary mercury sphygmomanometer
 TDP, terminal digit preference
 RZS, random-zero sphygmomanometer

BP is a physiologic measure of body functions, and it varies within quite narrow limits in healthy children at rest. Thus, an experienced observer has a quite accurate expectation of what the BP value in children is likely to be. This may lower high BP values and make low BP values higher if an OMS is used. Children's BP values are markedly lower than those of adults, and essential hypertension scarcely occurs at all in children (1–3). Thus, the accuracy of measurement of low BP values is even more crucial in epidemiologic surveys in children than it is in adults. This aspect is also important when evaluating the role of low BP in children as a negative risk factor, perhaps just as important as the recognition of high BP as a positive risk factor for coronary heart disease in adults.

Variability in BP measurements is caused by true variation and measurement errors, the latter being capable of arising both from the instrument and from the observer (4–10). Quality control of BP measurements is crucial in large-scale epidemiologic monitoring of BP. The use of tape recordings (Rose's tape) is one way of evaluating the differences between observers both within and between cross-sectional studies (4, 11). One of the well-known observer biases is TDP, *i.e.* the observer's preference to use a certain digit as the terminal digit of the BP reading. This leads to a systemic error in the recording of BP (9). To control TDP, a special device called an RZS has been developed by

Table 1. Numbers and ages of children whose BP was measured in Cardiovascular Risk in Young Finns project

Age (y)	Year		
	1980	1983	1986
3	537		
6	577	490	
9	645	519	483
12	651	568	481
15	602	538	487
18	537	438	412
21		334	335
24			302
Total	3549	2887	2500

Fig. 1. When listening to Rose's tape, observers record the times elapsed from the onset of each recording (time mark) to the appearance of K1, K4, and K5 by using stopwatches. The recorded times in s can be converted to mm Hg. For details, see Subjects and Methods.

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Fig. 2. Systolic, diastolic K4, and diastolic K5 BP values by age in girls (panels on the left) and boys (panels on the right) in the multicenter project Cardiovascular Risk in Young Finns. Ordinary sphygmomanometers were used in 1980 and 1983 (---) and an RZS in 1986 (—).

which TDP is changed from a systematic error to a random error (10, 12). The RZS has been recommended for use in epidemiologic surveys of BP (13), although it has also been criticized recently for giving lower BP values than OMS (14).

Because there are no reports on the use of an RZS in large-scale epidemiologic surveys of BP in children, we analyzed the BP measurements obtained in the Cardiovascular Risk in Young Finns survey and also analyzed data collected from repeated Rose's tape readings to evaluate the usefulness of Rose's tape for checking the quality of BP measurements.

SUBJECTS AND METHODS

Cardiovascular Risk in Young Finns is a multicenter project being carried out jointly by the five medical schools in Finland

(Helsinki, Turku, Tampere, Kuopio, and Oulu) in 17 areas. In each area, a random sample of individuals born in the years 1962, 1965, 1968, 1971, 1974, and 1977 was taken for the examination (15). Altogether 4320 persons were invited for the first examinations in 1980. Three cross-sectional surveys have been performed so far in which BP was measured in 3549 individuals aged 3–18 y in 1980 (survey I) and was monitored later in 2887 of the same individuals in 1983 (survey II) and in 2500 in 1986 (survey III) (Table 1). The exact sampling procedure is described in detail elsewhere (15).

BP measurement. BP was measured with an OMS in the first two surveys and in 1986 by using a Hawksley RZS (Hawksley & Sons, West Sussex, UK). Measurements were made after at least

Table 2. Results of Rose's tape readings performed after training sessions for Cardiovascular Risk in Young Finns project from 1980 to 1986*

Year	Korotkoff's phase		
	K1	K4	K5
1980	-0.84 (0.72)	12.70 (8.09)	3.68 (2.79)
1983	-2.07 (0.53)	5.53 (4.51)	0.12 (2.40)
1986	-0.82 (0.42)	6.68 (2.33)	-0.21 (3.24)

* Negative values indicate that BP phase was measured lower than correct value, and positive values that BP phase was measured higher than the correct value. K4 and K5 phases were significantly different from each other ($p = 0.002$) when tested with repeated measures analysis of variance. Results are given in mm Hg with SD (between nurses) in parentheses.

3 min of rest, from the right arm, with the subjects seated with the hand resting on the table. Two cuff sizes, 9.5×28 cm and 13×40 cm, were used according to the size of the subject's arm, to cover at least two thirds of the upper arm. All of the sphygmomanometers were checked daily for zero error and dirt in the tube. An ultrasound device was used to measure BP in the 3-y-old children in survey I, and therefore these measurements are not included in the present analyses.

The BP readings were taken to the nearest even value of mm Hg and were performed three times on each child. Systolic pressure was measured to K1, and diastolic pressure to K4 and K5. In survey III, four readings were taken, i.e. K1, K4, K5, and the random-zero value, which was deducted from the observed BP readings to obtain the real BP value for the individual. All three separate BP readings for each subject taken by the six nurses were included in the analyses of TDP. Altogether 14 nurses performed the BP measurements. Three of those nurses

participating in 1983 were the same as in 1980, whereas only one nurse in 1986 had participated earlier.

Rose's tape. Rose's tape recordings provide an opportunity to evaluate differences between observers (4, 11). When listening to Rose's tape, each observer hears a series of recorded pulse sounds. When the starting signal for each recording is heard, the observer sets the stopwatches in motion to record the time elapsing between this signal and the occurrence of the K1, K4, and K5 phases and the end mark of the recording (Fig. 1). Two stopwatches were used simultaneously, and the tape was listened to twice during each session, the first time for assessment of the time elapsing up to K1 and the total length of the recording and the second time for K4 and K5. The results were calibrated for the speed of the tape before analyses, and the times obtained in the readings were converted to corresponding pressure values (in mm Hg) to evaluate the variation between observers in measuring different phases of BP (K1, K4, and K5).

Training of nurses. In addition to listening to Rose's tape, the training sessions for the nurses also included recording BP values while watching a film showing a mercury manometer and listening to simultaneous pulse sounds (4, 9, 11) and recording BP by simultaneous measurements using double stethoscopes. The five local research teams consisted of four nurses, one of whom measured BP. This nurse was chosen after checking the nurses' ability to measure BP by reference to Rose's tape (9, 11). Rose's tape was used not only as a training aid but also as an objective control set for the observers (4, 9). One nurse was trained to take parallel measurements, and she visited each district twice during each survey (4). The same people were responsible for training the staff in each cross-sectional survey. Data on the occurrence of TDP in the readings made by each nurse in the earlier cross-sectional surveys were used in the later training sessions.

Statistical methods. The distribution of the terminal digit for each nurse was compared with the even distribution and tested

Fig. 3. Distribution of terminal digits (%) in BP values measured by each nurse in three cross-sectional surveys (1980, 1983, and 1986) conducted within the multicenter project Cardiovascular Risk in Young Finns. Panel 1986R represents the distribution of terminal digits after random-zero correction. Statistically significant TDP ($p < 0.01$) is indicated by an asterisk after the nurse code (N1-N14).

Table 3. χ^2 and respective p values for comparisons of distribution of terminal digits in BP readings made by nurses participating in Cardiovascular Risk in Young Finns project with an even distribution

1980			1983			1986		
N*	χ^2	p	N	χ^2	p	N	χ^2	p
N1	19.8	0.011	N1	17.5	0.025	N10	11.0	0.202
N2	80.5	<0.001	N7	28.2	<0.001	N11	9.8	0.279
N3	33.6	<0.001	N8	12.7	0.122	N12	26.5	<0.001
N4	35.7	<0.001	N4	13.8	0.087	N4	19.6	0.012
N5	40.3	<0.001	N5	63.6	<0.001	N13	15.7	0.047
N6	65.0	<0.001	N9	15.8	0.045	N14	32.6	<0.001
Total	274.9			151.6			115.2	

*N, nurse number.

with the Kolmogorov-Smirnov one-sample test. A χ^2 value for each nurse was calculated from the general contingency table. The distribution of BP values was examined by testing normality, skewness, and kurtosis in all age groups.

The slopes of the BP values plotted against age were compared using a one-way analysis of covariance. Correlations were calculated between random-zero levels and the measured corrected BP values. The Rose's tape readings were assessed using repeated measures analysis of variance.

RESULTS

The slopes of the lines demonstrating BP according to age in 1980 and 1983 differed from those in 1986, when the RZS was used ($p < 0.001$, one-way analysis of covariance), a continuous rise in BP with age being observed more clearly when the RZS was used (Fig. 2). This was especially true among the low BP values and for diastolic BP. The distribution of BP values obtained with an OMS did not differ significantly from that obtained with an RZS.

The systolic BP obtained in each age group and in both sexes with an RZS was consistently lower than that obtained with an OMS, and a similar trend was observed in diastolic K4 and K5 BP values (Fig. 2). The correlation coefficients relating the random-zero level to the corrected BP were all negative, *i.e.* -0.11 for systolic BP and -0.09 for both diastolic phases K4 and K5.

The mean values for the differences between the correct and actual BP readings in the Rose's tape recordings were -1.2 mm Hg (SD 2.1) for systolic BP, 8.3 mm Hg (SD 13.6) for diastolic K4, and 1.2 mm Hg (SD 7.0) for diastolic K5 BP, with a negative value indicating that the BP phase measured was lower than the correct value. K4 diastolic BP was significantly more difficult to measure accurately than K5 ($p = 0.002$), and K1 was consistently measured accurately (Table 2). The accuracy of K5 diastolic BP measurements improved from survey I in 1980 to survey III in 1986 (Table 2).

The distribution of the terminal digits differed significantly from the even distribution in all six nurses in both 1980 and 1986, whereas five nurses had a significant TDP in 1983 (Fig. 3). The frequency distributions of the terminal digits were quite similar on different occasions in the case of those nurses participating more than once (Fig. 3). The deviation of the distribution of the terminal digits from an even distribution decreased in each year when evaluated by the sum of the χ^2 values, *i.e.* from 274.9 in 1980 to 115.2 in 1986 (Table 3). Zero was the most commonly preferred terminal digit in 1980; three nurses (N2, N3, and N6) used it significantly more often than other figures. The situation had somewhat improved in 1983, but zero still represented 23.5% of all terminal digits and was preferred by two nurses (N5 and N7), and by four nurses (N10, N12, N13, and N14) in 1986 (Fig. 3). After deduction of the random-zero value, the terminal digits

were almost evenly distributed, with one nurse still having statistically significant TDP when tested with the χ^2 test, although it was of no practical importance (Fig. 3).

DISCUSSION

The fact that the age-related BP curves obtained with an OMS and an RZS differed significantly (Fig. 2) demonstrates that the rise in BP according to age is not linear when measured by OMS because of an observer bias. A similar trend can be seen in BP measurements obtained using an automated BP device (16). The difference in the shape between the BP curves suggests that low BP values are measured inaccurately by an OMS, rendering the range of values measured with an OMS artificially small and thus hampering the evaluation of BP as a risk factor. The BP curves obtained with an RZS are also in better accordance with results showing that there is a correlation between BP and body size, *i.e.* height and weight (3, 17).

The Rose's tape readings demonstrated that K5 is easier to measure accurately than K4 ($p = 0.002$), which is in accordance with the results of Rosner *et al.* (18), who reported that the reproducibility and predictive values for diastolic BP measurements in children are lower for K4 than for K5 and even suggested that systolic pressure alone could be used for screening for high BP in children. Because low BP in childhood may prove to be a protective factor, we believe that both systolic and diastolic BP should always be recorded but that K5 alone should be used as an indicator of diastolic BP in all age groups of children in clinical practice (17).

Rose's tape was found to be both a useful aid for training observers and a convenient means of quality control in epidemiologic surveys of BP. Nurses involved in clinical situations tend to be less well trained and to concentrate less on BP measurement than those engaged in epidemiologic surveys (19). Thus, when nurses doing clinical work are used as observers in epidemiologic projects, an RZS should be selected for measuring BP because it allows bias caused by TDP to be controlled and the observer is forced to concentrate better on the measurement of BP, which reduces the effects of any prior expectations (19).

Parker *et al.* (13) reported no significant difference in the distribution of terminal digits when well-trained, experienced observers measured BP repeatedly in adults using either an OMS or an RZS and concluded that the occurrence of TDP can be minimized by thorough training even when an OMS is used. Their opinion was that neither instrument is markedly superior to the other (13). Similar results on the occurrence of TDP were obtained by De Gaudemaris *et al.* (20). In our survey, the occurrence of TDP varied and it could not be abolished by training, although some improvement occurred as suggested by a decrease in the sum of χ^2 values (Table 3). The individual pattern of terminal digits for a given observer nevertheless changed very little even after extensive training and a long intervening period of time. Our results indicate that the bias caused by TDP in epidemiologic studies on BP may be large enough to hamper the formulation of reliable conclusions (4) and that it can be effectively controlled only by using RZS.

Methodologic surveys have been performed comparing simultaneous OMS and RZS-based measurements or randomized measurements of BP in the same subjects (13, 14, 19–21). These have shown that BP values obtained with an RZS are systematically lower than those obtained with an OMS, the difference being greater for diastolic than for systolic BP (14, 19–21), although greater difference in systolic than in diastolic BP has also been reported (13). The fact that our observers used the OMS and RZS devices in different surveys makes direct comparison between them impossible, but it is obvious that the values obtained with an RZS were systematically lower.

The systematically negative, although small, correlation coefficients between the random-zero value and the corrected BP value observed here support the suggestion that an RZS gives

lower BP values due to an observer bias (19), which may be influenced by the magnitude of the random-zero value (20). This slight negative correlation still cannot explain the differences observed in the slopes of the age-related BP curves, however (Fig. 2).

It can be concluded from the above that low BP values are measured more accurately when an RZS is used. This finding, in addition to the fact that it is only in this way that the bias caused by TDP can be effectively controlled, supports the use of an RZS in epidemiologic surveys among children, who generally have low BP.

REFERENCES

1. Report of the Task Force on Blood Pressure Control in Children 1977 *Pediatrics* 59:797-820
2. Kirkendall WM, Feinleib M, Freis ED, Mark AL 1981 AHA committee report. Recommendations for human blood pressure determination by sphygmomanometers. Subcommittee of the AHA postgraduate education committee. *Stroke* 12:555A-564A
3. Task Force on Blood Pressure Control in Children 1987 Report of the Second Task Force on Blood Pressure Control in Children—1987. National Heart, Lung, and Blood Institute. *Pediatrics* 79:1-25
4. Uhari M 1985 Evaluation of the measurement of children's blood pressure in an epidemiological multicentre study. *Acta Paediatr Scand [Suppl]* 318:79-88
5. McKeown T, Record RG, Whitefield AG 1963 Variation in casual measurements of arterial pressure in two populations (Birmingham and South Wales) re-examined after intervals of 3-4½ years. *Clin Sci* 24:437-450
6. Wilcox J 1961 Observer factors in the measurement of blood pressure. *Nurs Res* 10:4-17
7. Eilersten E, Humerfelt S 1968 The observer variation in the measurement of arterial blood pressure. *Acta Med Scand* 184:145-157
8. O'Brien I, O'Malley K 1979 The ABC of blood pressure measurement: the observer. *Br Med J* 2:775-776
9. Rose GA, Blackburn H, Gillum RF, Prineas RJ 1982 *Cardiovascular Survey Methods*, 2nd Ed. WHO monograph series no. 56
10. Rose GA, Holland WW, Growley EA 1964 A sphygmomanometer for epidemiologists. *Lancet* 1:296-300
11. Rose G 1965 Standardization of observers in blood pressure measurement. *Lancet* 1:673-674
12. Wright BM, Pore CF 1970 A random-zero sphygmomanometer. *Lancet* 1:337-338
13. Parker D, Liu K, Dyer AR, Giumetti D, Liao Y, Stamler J 1988 A comparison of the random-zero and standard mercury sphygmomanometers. *Hypertension* 11:269-272
14. O'Brien E, Mee F, Atkins N, O'Malley K 1990 Inaccuracy of the Hawksley random zero sphygmomanometer. *Lancet* 336:1465-1468
15. Åkerblom HK, Viikari J, Uhari M, Räsänen L, Byckling T, Louhivuori K, Pesonen E, Suoninen P, Pietikäinen M, Lähde P-L, Dahl M, Aromaa A, Sarna S, Pyörälä K 1985 Atherosclerosis precursors in Finnish children and adolescents. I. General description of the cross-sectional study of 1980, and an account of the children's and families' state of health. *Acta Paediatr Scand [Suppl]* 318:49-63
16. Zinner SH, Martin LF, Sacks F, Rosner B, Kass EH 1975 A longitudinal study of blood pressure in childhood. *Am J Epidemiol* 100:437-442
17. Uhari M, Nuutinen M, Turtinen J, Pokka T 1991 Pulse sounds and measurement of diastolic blood pressure in children *Lancet* 338:159-161
18. Rosner B, Cook NR, Evans DA, Keough ME, Taylor JO, Polk BF, Hennekens CH 1987 Reproducibility and predictive values of routine blood pressure measurements in children. *Am J Epidemiol* 126:1115-1125
19. Evans JG, Prior IAM 1970 Experience with the random-zero sphygmomanometer. *Br J Prev Soc Med* 24:10-15
20. De Gaudemaris R, Folsom AR, Prineas RJ, Luepker RV 1985 The random zero versus the standard mercury sphygmomanometer: a systematic BP difference. *Am J Epidemiol* 121:282-290
21. Labarthe DR, Hawkins CM, Remington RD 1973 Evaluation of performance of selected devices for measuring BP. *Am J Cardiol* 132:546-553