A Comparison of the Random-Zero and Standard Mercury Sphygmomanometers

DONNA PARKER, KIANG LIU, ALAN R. DYER, DANTE GIUMETTI, YOULIAN LIAO, AND JEREMIAH STAMLER

SUMMARY Both the standard mercury sphygmomanometer and the random-zero sphygmomanometer have been used in epidemiological studies and clinical trials. Problems arise in comparing studies since, in addition to other methodological differences, the readings obtained with the random-zero sphygmomanometer have been found to be lower than those obtained with the standard mercury sphygmomanometer. In the present study, blood pressures were measured in 66 subjects to examine the comparability of findings with the two instruments. Trained observers measured blood pressures simultaneously using a double-headed stethoscope and one cuff connected to the two sphygmomanometers. Use of instrument was randomly assigned for each blood pressure measurement; each observer was unaware of the other’s blood pressure reading. Readings were lower with the random-zero sphygmomanometer; mean difference ranged from 2.5 to 3.3 mm Hg for systolic pressure and 1.9 to 2.7 mm Hg for diastolic pressure. Digit distributions recorded by the two observers for the standard sphygmomanometer and the random-zero sphygmomanometer were not significantly different for either systolic or diastolic blood pressure. Intraindividual variation was greater with the random-zero sphygmomanometer than with the standard mercury sphygmomanometer. These data do not indicate that one instrument is clearly superior to the other, although in studies where the observer seeks to reduce the bias of multiple readings per person, the random-zero sphygmomanometer may be the more appropriate instrument. Critical to the use of either instrument are careful training, standardization, certification, and periodic recertification of observers.

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KEY WORDS • blood pressure determination • instrumentation

HIGH blood pressure (BP) is associated with an increased risk of cardiovascular disease.1-5 Therefore, optimal precision in measurement of BP is appropriate, especially in research studies. Accurate characterization of BP (e.g., in population studies or clinical trials) can be complicated by methodological, including instrumental, difficulties. BP measurement is subject to several sources of error that, in addition to intraindividual variability,6 limit valid classification of readings.

For many years, the instruments used to determine BP levels in the clinical and research setting have been the standard mercury sphygmomanometer and the aneroid manometer. An instrument used often in recent studies is the random-zero sphygmomanometer.7 When the standard mercury sphygmomanometer was compared with the random-zero sphygmomanometer in several studies, readings obtained with the latter were lower.8-10

We conducted an experiment to further assess the random-zero sphygmomanometer for use in epidemiological studies, based on the following specific issues: 1) Do BP readings obtained with the random-zero sphygmomanometer differ systematically from those obtained with the standard mercury sphygmomanometer? 2) Is end-digit preference with the random-zero sphygmomanometer reduced relative to that with the standard mercury sphygmomanometer when used by trained observers? and 3) Do the two methods differ in their intraindividual variation?

Materials and Methods

Instruments:

BPs were measured using a Velcro cuff of the correct width for the diameter of the participant’s arm,
connected by Y-tubing to a Hawksley random-zero sphygmomanometer (Hawksley & Sons, West Sussex, England) and a standard mercury sphygmomanometer (Baumanometer, Baum, Copiague, NY, USA).

BPs were taken simultaneously by two observers with a double-headed stethoscope connected to a single diaphragm. One observer used a mercury sphygmomanometer, the other used a random-zero sphygmomanometer. BP measurements were taken using the American Heart Association recommendations (with the minor modification of using the diaphragm) for human BP determination by sphygmomanometer.11

The random-zero sphygmomanometer is similar to the standard mercury sphygmomanometer except for a modification that obscures the true zero level of the mercury. This modification is achieved with a mechanical device located between the manometer column and the mercury reservoir; it draws variable amounts of mercury into an expandable chamber. The zero level of the mercury column is read after the systolic (SBP) and diastolic BP (DBP) have been measured and must be subtracted from these to obtain the true BP readings. The purpose is to allow the observer to obtain blind readings and thus reduce observer bias. Values for the random zero ranged from 0 to 20 mm Hg. Both devices were checked and calibrated before beginning the study.

Observers

Three experienced observers were employed. All three had recently been certified for BP measurement according to the Hypertension Detection and Follow-up Program protocol.12 The first observer (D.P.) measured BPs of all 66 participants; the second observer, 23 persons; the third observer, 43 persons.

Protocol

Sixty-six volunteers from the staff of the Department of Community Health and Preventive Medicine and the student body of Northwestern University Medical School participated in the study. Four BP measurements were taken in each participant by each pair of observers, two with the standard mercury sphygmomanometer and two with the random-zero sphygmomanometer. A randomization schedule was developed before beginning the study to determine which instrument each observer would use for each reading.

The participant was seated for 5 minutes before measurement of BP. The appropriate-sized cuff was then placed on the participant’s right arm. The observer using the standard mercury sphygmomanometer obtained the pulse obliteration pressure; the cuff was then reinflated to 60 mm Hg above that pressure. The tap to the random-zero sphygmomanometer mercury reservoir was closed after 5 seconds, and the cuff was then deflated at the rate of 2 mm Hg/sec. Both observers listened simultaneously through the double-headed stethoscope and recorded the SBP and fifth-phase DBP, which were rounded up to the nearest even digit. A 30-second pulse was then taken between each reading. Each observer was unaware of the other’s readings. Corrected BP levels for the random-zero readings were calculated after all four measurements were obtained.

Statistical Methods

The Statistical Package for the Social Sciences (SPSS; Chicago, IL, USA) was used for the calculations. Paired t tests were used to compare readings between standard mercury and random-zero sphygmomanometers. Chi-square analysis was used to determine if significant differences existed in end-digit preference with the two instruments.

Results

Mean age of the participants was 37 ± 12 years (median, 35 years; range, 22–70 years). Twenty-nine were men and 37 were women. Fifty-one were white, 10 were black, and five were Oriental.

Comparability of Observers

BP readings were combined for the second and third observers since there were no significant differences and are referred to as the second observer. Data on the means and standard deviations for the SBP and DBP measurements taken by Observers 1 and 2, based on the readings obtained with both instruments, are presented in Table 1. Mean SBP values were similar for the two observers. Mean DBP for the first and fourth reading by Observer 1 was slightly lower than that for Observer 2; the differences were statistically significant (p < 0.05). Otherwise, the readings of Observers 1 and 2 were closely comparable.

Comparison of Terminal Digit Preference with Random-Zero and Standard Sphygmomanometers

Percent distributions of the end-digits recorded with the standard mercury sphygmomanometer and of the end-digits of the adjusted BP with the random-zero sphygmomanometer are presented in Table 2. Percent distribution of end-digits was not statistically different between the two instruments for either SBP or DBP. Distributions of end-digits recorded by each observer

<table>
<thead>
<tr>
<th>Reading no.</th>
<th>SBP (mm Hg)</th>
<th>DBP (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td><strong>Observer 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>117.4</td>
<td>13.3</td>
</tr>
<tr>
<td>2</td>
<td>115.5</td>
<td>14.3</td>
</tr>
<tr>
<td>3</td>
<td>114.6</td>
<td>13.2</td>
</tr>
<tr>
<td>4</td>
<td>114.3</td>
<td>14.1</td>
</tr>
<tr>
<td><strong>Observer 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>118.1</td>
<td>15.2</td>
</tr>
<tr>
<td>2</td>
<td>113.6</td>
<td>14.2</td>
</tr>
<tr>
<td>3</td>
<td>114.1</td>
<td>14.7</td>
</tr>
<tr>
<td>4</td>
<td>113.5</td>
<td>14.3</td>
</tr>
</tbody>
</table>

Observer 2 is the combined readings of Observers 2 and 3 (see Results for details).

*p < 0.05, compared with respective DBP reading for Observer 1.
Comparison of Readings with Random-Zero and Standard Sphygmomanometers

Paired t tests for simultaneous readings with random-zero and standard mercury sphygmomanometers by the two observers are presented in Tables 3 and 4. Random-zero readings were significantly lower than those with the standard mercury sphygmomanometer, with a mean difference ranging from 2.5 to 3.3 mm Hg for SBP and 1.9 to 2.7 mm Hg for DBP.

Intraindividual variation between two readings using the same instrument is presented in Table 5. Calculations were based on the formula

\[ \sqrt{\frac{\sum d^2}{2N}} \]

where \( d^2 \) is the square of the difference between paired observations and \( N \) is the number of pairs. For both observers, for both SBP and DBP, intraindividual variation between the first and second reading was less with the standard mercury than with the random-zero sphygmomanometer.

Discussion

Random-zero readings in this study were significantly lower than those obtained with the standard mercury sphygmomanometer. The distributions of end-digits recorded by the observers were not significantly different between the standard mercury and the random-zero sphygmomanometer for either SBP or DBP. Intraindividual variation in reading the BPs of individual participants was greater with the random-zero than the standard mercury sphygmomanometer.

Several previous studies also found consistently lower BP readings with the random-zero than the standard mercury sphygmomanometer. Two studies used random assignment of manometer order and a third measured BPs simultaneously with the two sphygmomanometers. Differences were greater for DBP than for SBP readings. In the present study the difference was greater for SBP.

A previous study suggested that these differences with the two instruments may be due to mechanical differences between the two manometers. This inference was based on finding "no static difference between the devices at any calibration pressure and most of the difference was eliminated when the residual mercury was drained from the random-zero sphygmomanometer." An association with the height of the mercury column was also suggested since the difference was based on finding "no static difference between the devices at any calibration pressure and most of the difference was eliminated when the residual mercury was drained from the random-zero sphygmomanometer." Results from the present study do not support this possibility, since the difference was greater for SBP.

One potential source of variation eliminated in the present study is the order effect, which has also been examined recently in several other studies. It was previously thought that readings obtained with the random-zero sphygmomanometer were lower since they were obtained after initial readings with the standard mercury sphygmomanometer and BP tends to decrease in successive readings. In the present study, BPs were

### Table 2. Percent Distribution of Terminal Digit Preference in BPs

<table>
<thead>
<tr>
<th>Terminal digit (%)</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Random-zero</td>
<td>20</td>
<td>15</td>
<td>25</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>Standard</td>
<td>21</td>
<td>18</td>
<td>20</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>DBP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Random-zero</td>
<td>24</td>
<td>18</td>
<td>20</td>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>Standard</td>
<td>23</td>
<td>15</td>
<td>28</td>
<td>16</td>
<td>18</td>
</tr>
</tbody>
</table>

\( \chi^2 = 2.82, p > 0.50 \) for SBP; \( \chi^2 = 5.92, p > 0.10 \) for DBP.

### Table 4. DBP Readings with Random-Zero and Standard Mercury Sphygmomanometers

<table>
<thead>
<tr>
<th>Reading no.</th>
<th>Instrument</th>
<th>Mean (mm Hg)</th>
<th>SD</th>
<th>Mean difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Standard</td>
<td>119.1</td>
<td>14.3</td>
<td>2.5</td>
</tr>
<tr>
<td>1</td>
<td>Random-zero</td>
<td>116.6*</td>
<td>14.3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Standard</td>
<td>117.2</td>
<td>14.4</td>
<td>3.3</td>
</tr>
<tr>
<td>2</td>
<td>Random-zero</td>
<td>113.9*</td>
<td>14.1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Standard</td>
<td>116.2</td>
<td>13.9</td>
<td>3.1</td>
</tr>
<tr>
<td>3</td>
<td>Random-zero</td>
<td>113.1*</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Standard</td>
<td>115.6</td>
<td>14.0</td>
<td>3.3</td>
</tr>
<tr>
<td>4</td>
<td>Random-zero</td>
<td>112.3*</td>
<td>14.3</td>
<td></td>
</tr>
</tbody>
</table>

* \( p < 0.005 \), compared with values obtained using the standard mercury sphygmomanometer.
measured simultaneously with the two instruments and lower readings were consistently observed with the random-zero instrument.

It is possible that the differences observed between the two instruments are due to mechanical factors that cannot be explained by this study. The lower readings observed with the random-zero sphygmomanometer may also partially be explained by the fact that there are two sources of variation in readings with the random-zero sphygmomanometer instrument and only one with the standard mercury sphygmomanometer. The readings are rounded up twice with the random-zero sphygmomanometer; once for the BP reading and once for the zero reading. On the other hand, the reading is rounded up only once with the standard mercury sphygmomanometer. Since the subtracted random-zero value is inflated, there is the possibility that the reading obtained with the random-zero instrument will be lower than the reading obtained with the standard sphygmomanometer.

One stated advantage of the random-zero over the standard mercury sphygmomanometer is a decrease in end-digit preference. Results of the present study were that the digit preferences of the two observers were not significantly different with the two instruments. This finding indicates that, with appropriate training of staff, terminal digit preference can be decreased with use of the standard mercury sphygmomanometer.

Intraindividual variability of BP readings was less with use of the standard mercury than with the random-zero sphygmomanometer. This effect may be due in part to the fact that with the standard instrument the observer has knowledge of the previous reading, with a resultant biased decrease in variation. It may also be due to the fact that for the random-zero instrument the measure is the difference of two values with rounding errors. The apparently greater variation with the random-zero sphygmomanometer tends to decrease precision in the classification of a subject’s BP level based on two or more readings.

The question of which instrument to use for a given epidemiological or clinical study needs to be considered. The advantage of the random-zero sphygmomanometer is that it enables a single observer to take repeated independent BP readings on the same person since the observer is blind to the actual BP level until it has been recorded.7, 9 Disadvantages of this instrument include the need for mastery of specific details of technique, complaints from the subject of a tighter cuff since the pressure is increased to a level higher than with the standard instrument, and prolongation of the period of cuff inflation. Critical to the use of either instrument are careful training, standardization, certification, and recertification of observers.

Acknowledgment
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