Comparison of Two Automatic Blood Pressure Recorders and the Mercury Sphygmomanometer

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SUMMARY The Physiometrics automatic blood pressure recorder was compared with the mercury sphygmomanometer in 2200 children aged 5–14 years, each reexamined after 3 and 5 years; the Physiometrics recorder produced higher intrachild correlations. In trials we could transfer what were essentially Physiometrics readings into levels similar to mercury sphygmomanometric readings by filtering out the infrasonic frequency band. The Physiometrics USM-105 was compared with its successor, the Physiometrics SR-2, on 378 children aged 10–17 years. The SR-2 measured lower than the USM-105: 4.1 mm Hg systolic and 8.5 mm Hg diastolic; differences were larger in the younger children. Both in mean levels and correlations, SR-2 readings were closer to the mercury sphygmomanometer’s than were USM-105 readings, except or diastolic SR-2 readings, which were farther below the mercury sphygmomanometer 4th-phase readings than the USM-105. However, the SR-2 readings are likely closer to the true diastolic pressure in children 13 years and older, although we did not measure pressures intraarterially. Disc readings for systolic pressures showed coefficients of correlation averaging 0.96 among (n = 168) and 0.98 within (n = 40) readers for both models, but diastolic readings showed marked improvement from USM-105 (0.73, 0.81) to SR-2 (0.91, 0.97). In many of the parameters observed, SR-2 constitutes an improvement over USM-105. Automatic recorders offer certain advantages for measuring blood pressure in large-scale epidemiologic studies.

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KEY WORDS • blood pressure • blood pressure determination • epidemiology

BLOOD pressure levels have an important relationship to cardiovascular disease. Since hypertensive disease has such a high prevalence in our population, identification of individuals with high levels of blood pressure becomes critical for early management. Large differences observed in blood pressure levels may often be caused by methodological differences, instrumentation, observer bias, or the excitement and anxiety of the subject.

The mercury sphygmomanometer remains the standard instrument for blood pressure assessment in children, however, there are a number of potential advantages to automated electronic blood pressure recorders. Specialized areas such as measurement during anesthesia and care of infants have used such measurements for some time. A great need for improvement in blood pressure measurement in surveys exists. As part of a survey of a total population of children for early evidence of coronary artery disease and essential hypertension, we incorporated an automatic blood pressure recorder along with the mercury sphygmomanometer for assessing blood pressure measurements.

Methods

The purpose of this study was to answer several questions: How do readings from an automatic instrument selected during previous testing, a Physiometrics USM-105 automatic blood pressure recorder (Sphygmetrics, Inc., Woodland Hills, California), compare with those from the mercury sphygmomanometer in a large biracial population of children? What is the cause of differences and which instrument has the more useful readings? Since the Physiometrics USM-105 is now off the market, how does its successor, the SR-2, compare with it?
Selection of Physiometrics Instrument

The Physiometrics USM-105 automatic blood pressure recorder was selected for application in field studies to complement the mercury sphygmomanometer because of a detailed permanent record, ease of interim calibration, portability, sturdiness, ease of maintenance, and availability at a relatively low cost. The instrument has an infrasonic microphone (transducer) for locating over the brachial artery beneath an oversized rubber cuff bladder that entirely encircles the upper arm and is in turn enclosed in a rigid support. The transducer activates a stylus that records on a paper disc rotated by an aneroid manometer in open communication with the bladder. An updated model Physiometrics SR-2 was introduced by the Survigrams Company, and we obtained this instrument for comparison to the older version. The new model has a felt tip stylus instead of a fluid ink stylus, and has altered electronic circuitry (and presumably bandpass filters, although the manufacturer did not reveal details). Therefore, we were interested in comparing the two instruments.

General Methodology for Measuring Blood Pressure

Indirect blood pressures were obtained on the children by the mercury sphygmomanometer (W. A. Baum Company, Inc., Copiague, New York) and by the Physiometrics instruments. Selection of the bladder sizes for the mercury sphygmomanometer cuff were based on arm measurements, as reported earlier, and for the Physiometrics instruments we used one standard oversized rigid cuff model.

All blood pressure observers (registered and licensed practical nurses) were trained and tested initially and at regular intervals (four times) during each screening period on both the mercury sphygmomanometer and the automatic instruments.

The children were encouraged to void before the blood pressures were measured, and volunteer workers guided them through a designated random sequence for examination. For each child, the blood pressure was determined by multiple trained observers in a randomized sequence, each observer independently measuring three consecutive blood pressures per child. Two of these observers each used a well-illuminated mercury Baumanometer placed at eye level, and a third observer a Physiometrics recorder USM-105; a fourth observer used the Physiometrics SR-2 in the instrument comparison study. The automatic instruments were calibrated before use with the mercury column of the sphygmomanometer. Under quiet conditions, in a screened-off corner, observers recorded the first and fourth Korotkoff phases to determine the right arm blood pressure while each child was seated. The fifth phase was also recorded with sphygmomanometer readings but these readings were less consistent and are not part of this report. Care was taken to cover the brachial artery with the center of the rubber bladder. Physiometrics USM-105 discs were read blindly by the same field reader throughout the entire study period. A different reader was used to read the discs from the Physiometrics SR-2 since the layout of the disc barogram differs between the two instrument models. Reading of both models' discs by one field reader would not eliminate the potential bias (due to nonblindness as to model) and would have the added disadvantage of potential human error by interpreting according to two different protocols.

Studies of Physiometrics USM-105 vs Mercury Sphygmomanometer

Population

All Bogalusa, Louisiana, children, age 5 through 14 and later through 17 years, were eligible to be examined for cardiovascular risk factors in a manner described elsewhere. Such surveys were held during the school years 1973-74, 1976-77, and 1978-79, with participating rates respectively 93%, 89%, and 83% of those eligible.

Results

After 1 year of surveying, it seemed that the correlation coefficient of readings from the mercury sphygmomanometer were higher than those of the Physiometrics USM-105 instrument for systolic blood pressure: in 35 fifth-graders reexamined monthly for 8 months, the systolic correlations were consistently higher for the mercury sphygmomanometer, although for the diastolic measurements there was evidence that the reverse was true (table I). In 1101 children, ages 5, 8, 11, and 14 years, reexamined after 1 year, the means of the six measurements from the mercury sphygmomanometer also showed higher correlation

Table 1. Intrachild Correlation Coefficients of Blood Pressure Measured Monthly on Two Instrument Types in 35 Fifth Graders: Bogalusa Heart Study, 1974-1975

<table>
<thead>
<tr>
<th>Instrument</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hg sphygmo</td>
<td>0.81</td>
<td>0.84</td>
<td>0.84</td>
<td>0.84</td>
<td>0.80</td>
<td>0.83</td>
<td>0.78</td>
</tr>
<tr>
<td>Phys USM-105</td>
<td>0.72</td>
<td>0.68</td>
<td>0.72</td>
<td>0.76</td>
<td>0.73</td>
<td>0.67</td>
<td>0.70</td>
</tr>
<tr>
<td>Diastolic (4th phase)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hg sphygmo</td>
<td>0.65</td>
<td>0.50</td>
<td>0.47</td>
<td>0.58</td>
<td>0.60</td>
<td>0.47</td>
<td>0.44</td>
</tr>
<tr>
<td>Phys USM-105</td>
<td>0.57</td>
<td>0.59</td>
<td>0.70</td>
<td>0.60</td>
<td>0.65</td>
<td>0.72</td>
<td>0.50</td>
</tr>
</tbody>
</table>

During each measurement session, each child was measured 6 times by a mercury sphygmomanometer and 3 times by Physiometrics instrument USM-105, mean values were entered into the correlation computation.

*After combining the various correlation coefficients for each instrument using Fisher's Z scores, the systolic correlations differed significantly between instruments (p < 0.01), but not diastolic pressures.
TABLE 3. Correlation Coefficients for Blood Pressure Readings over 3 and 5 Successive Years in Children Initially Aged 2½–14 Years: Bogalusa Heart Study, 1973–1979

<table>
<thead>
<tr>
<th>Year</th>
<th>Instrument</th>
<th>No.</th>
<th>Year 1</th>
<th>Year 4</th>
<th>Year 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hg sphygmanometer</td>
<td>2221</td>
<td>0.57</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Physiometrics USM-105</td>
<td>2187</td>
<td>0.66*</td>
<td>0.63*</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Physiometrics USM-106</td>
<td>2187</td>
<td>0.43</td>
<td>0.48</td>
<td></td>
</tr>
</tbody>
</table>

For ages 2½–5 years, a different infrasonic instrument, the Infrasonde 3000 (Marion Scientific Corporation, Costa Mesa, California), was used because at this age an audible signal was preferred over a recorded signal.

*Physiometrics coefficient was larger than that of the mercury sphygmanometer, p < 0.0001; sphygmanometer values = means of 6 measurements on each child; Physiometrics values = means of 3 measurements on each child.

TABLE 2. Intrachild Correlation Coefficients (Year 1 vs Year 2) of Blood Pressure on Two Instrument Types, by Age, Race, and Sex. Bogalusa Heart Study, 1973–1975

<table>
<thead>
<tr>
<th>Age at year 1 (years)</th>
<th>Instrument</th>
<th>WM</th>
<th>WF</th>
<th>BM</th>
<th>BF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic</td>
<td>Hg sphygmo</td>
<td>0.47</td>
<td>0.69</td>
<td>0.52</td>
<td>0.58</td>
</tr>
<tr>
<td>5</td>
<td>Phys USM-105</td>
<td>(81)</td>
<td>(74)</td>
<td>(43)</td>
<td>(35)</td>
</tr>
<tr>
<td>8</td>
<td>Phys USM-105</td>
<td>0.59</td>
<td>0.55</td>
<td>0.57</td>
<td>0.52</td>
</tr>
<tr>
<td>11</td>
<td>Phys USM-105</td>
<td>0.61</td>
<td>0.68</td>
<td>0.68</td>
<td>0.71</td>
</tr>
<tr>
<td>14</td>
<td>Phys USM-105</td>
<td>0.62</td>
<td>0.62</td>
<td>0.61</td>
<td>0.72</td>
</tr>
</tbody>
</table>

During each measurement session, each child was measured 6 times by mercury (Hg) sphygmanometer and 3 times by Physiometrics; mean values were entered into the correlation computation. Sample size is given in brackets.

WM = white male; WF = white female; BM = black male; BF = black female.

Coefficients than the mean of three measurements by Physiometrics for 14 of 16 age-race-sex groups for systolic levels, and for 11 of 16 groups for diastolic levels (table 2). However, after 3 and 5 years an apparent reversal occurred, and now the systolic readings from the Physiometrics USM-105 instrument had slightly greater correlation coefficients (table 3). Correlation coefficients over a shorter time span (table 2) may in part reflect the somewhat lower reliability of three Physiometrics measurements vs six mercury sphygmanometer measurements. On the other hand, the Physiometrics instrument, in spite of providing only half as many readings as the mercury sphygmanometer, seemed to predict the blood pressure of the same child after 3 and 5 years better than the mercury sphygmanometer. The superior correlation of the Physiometrics instrument, however, was not noted when correlations were specific for age, race, and sex (data not reproduced here).

A comparison of systolic blood pressure percentiles for the two instrument types revealed that the Physiometrics USM-105 reads higher, more so in the older black boys of the upper percentiles (fig. 1). This is the group of children at highest risk of hypertension.

Validation Trial of Physiometrics Blood Pressure

To conduct a preliminary study of this difference, we used a Korotkoff Sound Microphone (Narco Biosystems, Inc., Houston, Texas) with a bandpass filter that removed the 10–50 Hz infrasonic signals. The Physiometrics USM-105 "bias" of elevated systolic levels was reproduced in four 15- to 38-year-old volunteers by connecting the microphone to a polygraph that also registered the cuff pressure through a gain-zero pressure transducer (Narco Biosystems, Inc.), and could be connected with the Physiometrics instrument to record output. When the bandpass filter was switched in series with the microphone, the "Korotkoff sounds" became identical to those heard by ear using the stethoscope (table 4).

TABLE 4. Systolic Blood Pressure Readings (mm Hg) with Two Instruments, One with Removable Infrasound Filter, in Four Subjects — Preliminary Study

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Korotkoff sound microphone</th>
<th>Hg sphygmanometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Race</td>
<td>Sex</td>
</tr>
<tr>
<td>----------</td>
<td>------</td>
<td>-----</td>
</tr>
<tr>
<td>17</td>
<td>W</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>(repeat)</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>B</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>(repeat)</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>B</td>
<td>F</td>
</tr>
<tr>
<td>38</td>
<td>B</td>
<td>M</td>
</tr>
</tbody>
</table>

*Readings without filter are identical to readings on Physiometrics USM-105.
†This filter removed 10–60 Hz infrasonic signals.

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These observations suggest that, when the cuff is inflated above the systolic level in the presence of high-energy myocardial contraction, the infrasonic signal created proximal to the cuff is transmitted through the occluded brachial artery to be recorded as a "false" (higher) first phase by the Physiometrics instrument and by the unfiltered microphone, but neither by the filtered microphone nor by the human ear. If myocardial contraction did not produce transmitted energy, the Physiometrics and mercury sphygmomanometer systolic levels would coincide. Whitcher has shown that the infrasonic band of the sonic spectrum of the Korotkoff signals carries most of such energy.

Studies of Physiometrics USM-105 vs SR-2 Model Population

Franklinton, Louisiana (25 miles west of Bogalusa) school children were examined for cardiovascular risk factors in the same manner as described elsewhere. After parental consent was obtained, 378 children aged 10-17 years were examined, and had no missing observations.

The handling of each Physiometrics instrument and the reading of the discs were performed following the respective manuals issued by the manufacturer. In each child, blood pressure was measured by four in-

FIGURE 1  Selected percentiles of blood pressure on Physiometrics USM-105 instrument compared to mercury sphygmomanometer, by race and sex for children ages 5-17 years. Hatched areas indicated where Physiometrics readings are higher than mercury sphygmomanometer readings. Bogalusa Heart Study, 1976-1977.
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Instruments: Two mercury sphygmomanometers, the Physiometrics USM-105 instrument, and Physiometrics SR-2, in a rigidly randomizing sequence. After completion of the morning's examinations (approximately 20 children were examined by one of two teams using four instruments each), a sealed envelope was opened and a 10% random sample of these children was reexamined by the same observer in the same order of instruments, thus providing a measurement of intraobserver reliability. These observations resulted in an observer error (standard error) of 4–5 mm Hg systolic and diastolic (4th phase) for each of the instruments.

To exclude differences in personal style of using the instrument, measurement by the observers as a cause of differences in results was studied by multiple linear regression techniques, controlling for individual observer effect. Subject effects were eliminated by using as the dependent variable the difference in pressure on the same child as measured by the two automatic instrument models, randomizing the order in which the blood pressure of the child was measured by these instruments.

For each of the two instrument models, 168 of the total possible 1218 discs were blinded and given a five-digit random identification code. In addition, these discs were read by two outsiders, Readers A and B, who each read and retained the disc-reading protocols as issued in various communications by the manufacturer. In addition, Reader B had previous experience in disc reading, whereas Reader A had not. Of the 168 discs for each model, 40 were reassured to the readers for assessment of within-reader variability for each model.

Although we had retraining sessions with all blood pressure observers every 3 months, this did not eliminate the need for continuous quality control of the measurements. We found that one observer during 1 year of cross-sectional study, within a 6-month period drifted in measurement interpretation and systematically proceeded to misinterpret the diastolic Korotkoff sounds. Diastolic readings of this observer over this period were therefore eliminated.

Results

The resulting blood pressure levels (± 2 SE) of the four instruments used (for results of the two mercury sphygmomanometers, combined means were given only) are given by age in figure 2.

The relationship between the Physiometrics USM-105 and mercury sphygmomanometer was much like that previously found in the Bogalusa Heart Study4 and reported above. However, for younger children the Physiometrics SR-2 yielded lower values than the USM-105 for systolic pressure (11 mm Hg difference for 10-year-olds) and especially for diastolic pressures (10–11 mm Hg difference for 10- to 14-year-olds, and more for the younger children). The differences detected in these studies were of the same magnitude for white and black children, and for children in the upper and lower blood pressure percentiles.

Table 5 presents means ± 2 SE for the various instrument types. The Physiometrics SR-2 on the average measured lower than the Physiometrics USM-105: 4.1 mm Hg systolic and 8.6 mm Hg diastolic. In comparison to the mercury sphygmomanometer,
Physiometrics model SR-2 measured only 0.5 mm Hg higher for systolic, and 6.9 mm Hg lower for diastolic. The latter, however, was in comparison to 4th-phase readings by the mercury sphygmomanometer, which is reputedly slightly higher than the true intraarterial pressure^{11} (not measured by us).

Table 6 presents Pearson coefficients of correlation between the readings of the various instruments. For systolic pressures the correlations between instrument types are lower than those within instrument types (between models). For diastolic (4th phase) pressures the SR-2 shows higher correlation than does the USM-105 \( (p < 0.05) \) with the mercury sphygmomanometer.

The results of the multiple regression analysis of measurement differences between automatic instruments are shown in Table 7. Yearly decrements for systolic and diastolic pressure respectively were 0.72 and 0.92 mm Hg. These decrements of reading differences with larger children were statistically highly significant \( (p < 0.0001) \) when controlling for...
observer effect, and they were larger for diastolic than for systolic recordings. Multiple regression coefficients squared were 0.17 (systolic) and 0.22 (diastolic).

Pearson coefficients of correlation within and among disc readers are given in Table 8. For systolic readings, coefficients of correlation averaged 0.96 among readers and 0.98 within readers. However, for diastolic readings, coefficients of correlation were low for model USM-105 (0.73, 0.81), but they improved when using model SR-2 (0.91, 0.97).

Table 9 gives means ± SD both within and among readers, and here again the SR-2 mean diastolic readings showed a decreased difference when compared to the USM-105. It should be noted that the paired t test will be significant as long as the differences within each child are consistent, and hence the significance of this test may not reflect the suitability of the instrument.

Although the nature of the barogram on the paper disc in our present study prevented readings from being blind to the instrument model, readings were blind to the child’s age, sex, and race, and the readers were unaware of the hypotheses tested.

### Discussion

Potential advantages of automatic blood pressure equipment include: decrease of observer fatigue so that more measurements can be made by the same observer; elimination of the human element in various measurement phases, so that the subject’s reaction to the observer can now be studied as one of the remaining human elements affecting blood pressure measurement; observation of the same subject over time becomes more feasible as certain sources of measurement variation are eliminated; and with more sophisticated automation it becomes feasible to study moment-to-moment blood pressures under conditions of customary activity.

The apparently improved correlations of the Physiometrics USM-105 compared to the mercury sphygmomanometer over 3–5 years (when races, sexes, and ages are grouped together) was unexpected after we had observed its relatively low correlations over shorter periods of time. Apparently, the energy involved in the myocardial contraction as sensed by the infrasonic transducer contributes to the Physiometrics “prediction” somewhat independently of the “true” systolic pressure level. We speculate that the Physiometrics instrument is more sensitive than the mercury sphygmomanometer to energy transmitted via low-frequency vibratory signals, and thus more sensitive to the detection of left ventricular hypertrophy, which may be more prevalent in blacks than in whites at comparable levels of blood pressure recorded at one moment in time. These readings may by themselves be more predictive of future hypertension. Pending a more elaborate validation trial on a large representative sample of subjects, it is suggested that the Physiometrics USM-105 instrument, and modified versions for automatic recording, although not necessarily more valid and more reliable than the mercury sphygmomanometer, have the potential of being useful to follow blood pressure levels over time in an effort to be predictive of future hypertension. This warrants more laboratory experimentation and use of other instruments over time in epidemiologic studies for comparative data.

From the Franklinton observations, we conclude that both in mean levels and in correlations, the SR-2 readings were closer to the mercury sphygmomanometer readings than were the USM-105 readings. An exception was the mean diastolic readings when compared to the mercury sphygmomanometer 4th-phase
readings, where the mean difference was larger for the SR-2 than for the USM-105; in this case, however, the SR-2 readings may be closer to the true diastolic pressure, although we did not take intraarterial measurements. Systolic disc readings showed coefficients of correlation averaging 0.96 among readers (n = 168) and 0.98 within readers (n = 40), but diastolic readings showed a marked improvement from USM-105 to SR-2. In a number of observed parameters, SR-2 constitutes an improvement over USM-105.

The Physiometrics model USM-105 instrument has certain potential advantages over the mercury sphygmomanometer, but this early model has been taken off the market. Its successor, the Physiometrics SR-2 instrument, seems to produce levels closer to mercury sphygmomanometer reading and has better replicability than the Physiometrics USM-105 automatic pressure recorder. More laboratory experimentation is warranted to arrive at a reliable automatic instrument that can be helpful in predicting future hypertension. Epidemiological field studies are needed to test out newly developed automatic blood pressure recording instruments.

Acknowledgments

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