COMPARATIVE PERFORMANCE OF THE MERCURY SPHYGMOMANOMETER AND DIGITAL SPHYGMOMANOMETER

Supported by tetfund TERTIARY EDUCATION TRUST FUND

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Received: August 16, 2021 **Accepted:** October 07, 2021

Abstract: Of the three mainly used non-invasive modalities for the accurate measurement of subjects' systolic and diastolic blood pressure, the mercury sphygmomanometer is the most widely accepted and used. However due to concerns of toxicity in the usage and disposal of mercury, several countries have directed policies to minimize the use of mercury instruments. The digital sphygmomanometer is also widely used since it is relatively cheaper, non-toxic and does not require auscultation skills to obtain blood pressure readings. However the concern is the accuracy and validity in the values obtained for systolic and diastolic blood pressure using the digital/automated sphygmomanometer. This study is posed on the evaluation of the validity and accuracy in comparison between mercury sphygmomanometer and the digital sphygmomanometer. Fifty (50) subjects were selected using the simple random sampling techniques from among male and female above 18 years old that complied with all instructions and met the inclusion criteria for this study. The study samples used were recruited on notice and home visits by taking blood pressure measurement using left and right arm. Findings from this study implied that there is a significant difference in the systolic blood pressure values obtained using the manual sphygmomanometer and the digital sphygmomanometer in the left arm ($p=0.005$) and in the right arm also ($p=0.000$). There is no difference however in the diastolic blood pressure values obtained using the manual sphygmomanometer and the digital sphygmomanometer in the left arm ($p=0.174$) and in the right arm ($p=0.226$). Findings from this study also showed a non-significant inter-arm difference (IAD) between systolic blood pressure using manual sphygmomanometer (0.34 ± 1.22) and using digital sphygmomanometer (0.35 ± 1.28). Likewise there is a non-significant inter-arm difference (IAD) between diastolic pressure using manual sphygmomanometer (2.43 ± 1.60) and using digital sphygmomanometer (2.07 ± 1.27). Based on the findings of this study it was concluded that the digital sphygmomanometer is reliable in terms of measuring systolic blood pressure, but in measuring lower blood pressures care must be taken in the use of digital sphygmomanometers.

Keywords: Blood pressure, diastolic, digital, mercury, sphygmomanometer, systolic

Introduction

Blood pressure (BP) is a basic vital sign and one of the most important physiologic signals regarding cardiovascular and heart diseases. Problems of the cardiovascular system affecting the heart or the blood vessels such as local stenosis, or peripheral vascular disease and hypertension are highly related to BP (Clark *et al*., 2012). To measure the BP, various types of BP monitoring devices are being used in hospitals. Blood pressure can be obtained by invasive or non-invasive means, depending on the ability to use the instrument properly for the measurement (Taksande *et al*., 2015). Of the three mostly used non-invasive medical procedures to check blood pressure throughout the world, the manual mercury sphygmomanometer is considered the "gold standard" that is used, if used by a trained nurse or doctor (Ogedegbe and Pickering, 2010). The other two are aneroid meter and the automated oscillometric device, which are rarely used.

Currently, it is being debated whether mercury sphygmomanometer should be replaced with the automated oscillometric devices because of health concerns. Mercury has been banned in various European countries such as Sweden and the Netherlands as well as in the United States due to its toxic nature (Ogedegbe and Pickering, 2010; O'Brien, 2002).

Traditionally, blood pressures have been measured using a manual mercury sphygmomanometer, but in recent years the use of automated blood pressure machines such as the Dinamap and Omron have been the trend in most hospitals (Jones *et al*., 2003). However, many nurses question the accuracy and reliability of these machines when used in the clinical setting and still prefer the manual sphygmomanometer which is considered the 'gold standard' when used by a trained observer (Butani and Morgenstern, 2003; Mohan *et al*., 2004; Bagga *et al*., 2007). There is some evidence in the literature that digital monitors are reliable and accurate when compared with other devices, such as the aneroid or mercury devices (Butani and Morgenstern, 2003; Sigurdsson *et al*., 1996; Carney *et al*., 1999; O'Brien *et al*., 2001). This type of equipment can replace the manual sphygmomanometer in some contexts, such as at home or in epidemiological studies within the community. However, most studies were done only on adults, and therefore, the reliability of automated blood pressure machines among children is unclear.

Although the mercury sphygmomanometers are considered accurate for the non-invasive estimation of Blood Pressure for a long time now (British Hypertension Society, 2006), but due to toxicity of mercury and potential health risks associated with mercury usage and disposal, mercury instruments are really going out of use worldwide. Likewise the European Union directed phasing out of using mercury instruments. In this vein, non-mercury instruments are being considered to replace the mercury sphygmomanometers such as the aneroid and the digital sphygmomanometers.

Additional advantage of aneroid instrument is the portability (A'Court *et al*., 2011), while that of digital instruments relatively easier since the examiner does not rely on the auscultation skills to get accurate results. In a large study at this outset in UK by A'Court *et al*. (2011) in which Six hundred and four sphygmomanometers were identified consisting of 323 digital (53%), 192 aneroid (32%), 79 mercury (13%), and 10 hybrid (2%) devicesexamining the comparability of measurement accuracy of all the three categories of sphygmomanometer and found that digital instruments are as accurate as mercury instruments, while aneroid sphygmomanometers showed higher failure rate. This therefore led the authors to recommend the use of digital sphygmomanometers considering the relative affordability and ease of use.

Furthermore certain factors calls for concern on the use of the manual blood pressure measuring instrument such as the site of placement of the cuff, the size of the cuff, type of stethoscope, following the proper protocol, patient's age group, pregnancy, exercise, arrhythmias and the white coat response (O'Brien *et al*., 2003). Errors in blood pressure measurement could also result when the nurse or the doctor is conversing while taking the measurement and whether there is background noise or silence (Reeves, 1995; Le Pailleur *et al.*, 1998). All these factors selectively or collectively could contribute towards possible inaccurate BP readings, with a potential for misdiagnosis.

Inter-arm difference (IAD) indicating differences in the values of blood pressure reading between the right and left arms of ≥ 10 mmHg is important because significant IAD in BP may indicate the presence of congenital heart disease, peripheral vascular disease, unilateral neurological, musculoskeletal abnormalities, or aortic dissection (Perloff *et al*., 1993). However, even when the IAD has seemingly no pathological background, relevant IAD (≥ 10 mmHg) are still important to know, as office measurements consequently performed at the arm with lowest BP can lead to a wrong diagnosis and under treatment of hypertension (Clark *et al*., 2009). In addition, to verify the effectiveness of antihypertensive therapy it is of clinical significance that BP is measured in the same arm on all sequential occasion.

This study is to evaluate the validity and accuracy between mercury sphygmomanometer and digital sphygmomanometer using healthy subjects in medical settings.

Materials and Methods

Study setting

A cross sectional study which was conducted in two locations, among students of Olabisi Onabanjo University (OOU), Faculty of Basic Medical Science, Sagamu Campus, Sagamu, Ogun State, Nigeria and in residents of Ikenne Remo in Ikenne Local government area, Ikenne, Ogun State, Nigeria. 50 subjects chosen randomly from among male and female above 18 years old were used in the study, who voluntarily complied with all instructions and this was done on notice and home visits by taking blood pressure measurement using left and right arm.

This study was designed to compare an automated blood pressure apparatus and manual blood pressure apparatus using the same arm and also to determine if inter-arm differences (IAD) of both systolic and diastolic blood pressure exists using both modalities. An inclusion criterion was a healthy individual with no known history of serious illness and exclusion criteria were upper limb amputation, cuts or bruising of the skin at measurement sites, peripheral vascular disease and congenital heart disease.

Data collection

Data were collected by interviewing subjects with the aid of questionnaire. The information gathered from subjects was;

A. General Characteristics;
- i) Sex
- ii) Age
- iii) Occupation

B. Measurements
- i) Weight (kg)
- ii) Height (m)
- iii) Blood pressure readings I and II (mmHg)
- iv) Body Mass Index (BMI) (kg/m^2)
- v) Pulse rate (bpm)

Experimental materials

The materials used for this research were;

1. Stethoscope
2. Mercury sphygmomanometer
3. Automatic Blood Pressure Monitor (Omron Healthcare, 2013)
4. Bathroom Weighing Scale (CAMRY Model : BR9012)
5. Local Made Calibrated Meter Rule
6. Tape Rule
7. Questionnaire paper

Measurements

The weight, height, systolic pressure, diastolic pressure and pulse rate were carefully measured.

Procedure in blood pressure and pulse rate measurement

i. Subjects participating were allowed to rest for 10 minutes in an area not totally free of noise.
ii. The subjects were told to sit upright, back supported, place their feet flat on the floor and place the arm on the table so that the cuff is placed on the arm and made sure it is at the same level with the heart.
iii. The apparatus was positioned in such a way as to prevent subjects from seeing the readings as they were taken.
iv. The automated apparatus was operated by pressing the O/I START button and the cuff inflates automatically. When measurement is complete the monitor displays the blood pressure and the pulse rate, and automatically deflates the cuff (Omron Healthcare, 2013)
v. For each subject the arm to be used first was chosen at random.
vi. Two blood pressure readings were taken using each apparatus (Taksande *et al*., 2015).
vii. Without changing cuff placement, two successive readings were taken for an arm. Two readings from mercury sphygmomanometer and two readings from automatic sphygmomanometer in participant using left arm and right arm sequentially, making eight (8) readings.
viii. There was 5 minutes break between mercury and automatic readings taken.
ix. All measurements were obtained under similar conditions except for two different Bp apparatus used.
x. Blood pressure was recorded in millimetres in mercury (mmHg).

Height

A portable built local made rod (carefully calibrated with the aid of meter rule) was used to measure the height of subjects. Individual height was measured with no head gears and face caps on, as well as no foot wears. Before the readings were taken the subject were requested to have feet together, heels against wall on a levelled ground, knees straight and look straight forward ahead with which the calibrated rule was placed on the wall. Height was recorded in meters (m).

Weight

Weight was measured using the CAMRY Mechanical Personal Scale Model; BR9012. Light clothing was put on. Subjects were asked to stand on the weighing scale, face-forward and place arm on same sides of the body.

Weight was recorded in kilograms (kg).

Body mass index (BMI)

The BMI was calculated by dividing weight by the square of the height in meters. BMI is measured in kg/m.

$$BMI = \frac{weight\,(kg)}{height\,(m)}$$ (Singer-Vine, 2009)

Statistical analysis

The data collected were analysed using SPSS 15.0 version software (Norusis, 1998). Comparison of mean ± SEM of blood pressure measurements (systolic, diastolic) between automated blood pressure apparatus and manual blood pressure apparatus, pulse rate, in the same arm (left arm or right arm). Significant difference between the variables were determined using the paired T-test. Statistical significance was set at $p < 0.05$*.

Results and Discussion

50 subjects that participated were chosen randomly from among men, women, ladies and gentlemen all above 18 years old. There were 19 (19%) male and 31 (31%) female of different occupations. There were 8 series of blood pressure (BP) measurements for left and right arm taken in fifty (50) subjects totalling four hundred (400) readings with an average of two hundred (200) readings.

In left arm, BP taken with the automated device mean ± SEM was systolic 118.00 ± 2.18 mmHg and diastolic 76.67 ± 1.60 mmHg compared to systolic 114.25 ± 2.32 mmHg and diastolic 74.20 ± 0.98mmHg measured by manual mercury sphygmomanometer BP readings at ($p<0.05$). In right arm, BP taken with the automated device mean±SEM was systolic 118.43 ± 2.25 mmHg and diastolic 73.97 ± 1.51 mmHg compared to systolic 112.71 ± 1.89 mmHg and diastolic 76.47 ± 1.62 mmHg measured by manual mercury sphygmomanometer BP readings at ($p<0.05$).

As shown in Table 1, the general characteristics of the respondents indicated that the study samples were quite younger, majorly females and comprised of more students. Likewise, most of the subjects of this study were non-obese individuals. But there were more overweight individuals than underweight ones.

Table 1: General characteristics of the respondents

Variables	Frequency n=50	Percentage (%)
Age		
11-20	17	34.0
21-30	18	36.0
31-40	7	14.0
41-50	4	8.0
51-60	2	4.0
61-70	2	4.0
Gender		
Male	19	38.0
Female	31	62.0
Occupation		
Artisan	6	12.0
Business	17	34.0
Civil Service	4	8.0
Student	23	46.0
Weight		
<50Kg	6	12.0
50 – 70 Kg	35	70.0
>70 Kg	9	18.0
Height		
1.51 - 1.60	17	34.0
1.61 - 1.70	21	42.0
>1.70	12	24.0
Body Mass Index (BMI)		
<18.5	5	12.0
50 – 70 Kg	33	66.0
>25	12	24.0

Table 2: The mean ± SEM and standard deviation of blood pressure and pulse rate values obtained using both manual and digital sphygmomanometers on both right and left arm

Variables	N	Mean±Std. Error Mean	Standard deviation
Left systolic manual	50	112.74±1.81	12.64257
Left systolic auto	50	117.68±2.19	15.38793
Left diastolic manual	50	73.95±.97	6.81897
Left diastolic auto	50	75.86±1.51	10.56626
Right systolic manual	50	112.39±1.89	13.28179
Right systolic auto	50	118.04±2.26	15.80511
Right diastolic manual	50	76.39±1.65	11.55196
Right diastolic auto	50	73.79±1.51	10.59972
Left arm pulse	50	79.64±1.49	10.43881
Right arm pulse	50	79.60±1.79	12.58222

Table 2 showed that the mean SBP ± SEM (112.74 ± 2.81 mmHg) and DBP ± SEM (73.95±.97 mmHg) in left arm using the manual sphygmomanometer which was lower when compared to the values of SBP ± SEM (117.68±2.19 mmHg) and DBP ± SEM (75.86±1.51 mmHg) obtained the digital sphygmomanometer.

Likewise the mean SBP ± SEM (112.39±1.89) in the right arm using the manual sphygmomanometer was lower when compared to the values of SBP ± SEM (118.04±2.26 mmHg) using digital sphygmomanometer whereas the value of DBP ± SEM (76.39±1.65 mmHg) obtained using the manual sphygmomanometer was more than the value of DBP ± SEM (73.79±1.51 mmHg) obtained using the digital sphygmomanometer.

Table 3: T-test statistics of the blood pressure and inter-arm difference values between manual sphygmomanometer with the digital sphygomomanometer

	Variables	Difference in mean	Standard Deviation	t	df	Sig. (2-tailed)
Pair 1	Leftsystolic manual - leftsystolic auto	-4.93878	11.60353	-2.979	49	.005
Pair 2	Left diastolic manual - left diastolic auto	-1.89796	9.63445	-1.379	49	.174
Pair 3	Right systolic manual - right systolic auto	-5.63878	9.11877	-4.329	49	.000
Pair 4	Right diastolic manual - right diastolic auto	2.61224	14.89871	1.227	49	.226
Pair 5	Left systolic Manual - right systolic manual	.34694	8.55570	.284	49	.778
Pair 6	Left diastolic manual - right diastolic manual	-2.43878	11.25446	-1.517	49	.136
Pair 7	Left systolic auto - right systolic auto	-.35306	8.96775	-.276	49	.784
Pair 8	Left diastolic auto - right diastolic auto	2.07143	8.91043	1.627	49	.110

p = Sig. (2-tailed)

The left arm pulse (79.64±1.49) was slightly higher than the right arm pulse (79.60±1.79).

The result in Table 3 revealed a significant outcome (p=0.005), since the p-value is lower than the level of significance (0.05). This outcome implied that there was significant difference in the systolic blood pressure values obtained using the manual sphygmomanometer and the digital sphygmomanometer in the left arm, whereas there was no difference (p = 0.174) in the diastolic blood pressure values obtained using the manual sphygmomanometer and the digital sphygmomanometer in the left arm. This paired statistics also indicated a significant difference (p =0.000) in the systolic blood pressure values obtained using the manual sphygmomanometer and the digital sphygmomanometer in the right arm, whereas there was no difference (p = 0.226) in the diastolic blood pressure values obtained using the manual sphygmomanometer and the digital sphygmomanometer in the right arm.

Table 3 showed non-significant inter-arm difference (IAD) between systolic blood pressure using manual sphygmomanometer (0.34±1.22) and using digital sphygmomanometer (0.35±1.28). Likewise, there was a non-significant inter-arm difference (IAD) between diastolic pressure using manual sphygmomanometer (2.43±1.60) and using digital sphygmomanometer (2.07±1.27).

In this study comparison between automatic blood pressure apparatus OMRON M2 BASIC and manual blood monitor (mercury sphygmomanometer) using the same arm (either left arm or right arm) chosen randomly was done on 50 subjects. The subjects of which include artisan, business man / woman, civil servants and students whom all responded with the aid of questionnaire as a research tool for data collection.

During the course of the experiment, in other not to predict BP measurements, the use of mercury sphygmomanometer was done first followed by the use of automatic sphygmomanometer.

However, the guarantee of the automated apparatus (OMRON M2 BASIC) was done on March 2nd, 2021. The apparatus were maintained according to manufacturer recommendations all of which there was confidence in validity of apparatus before, during and after the course of the research.

Many measurements used in comparing shows that there were lots of differences between the two apparatus using blood pressure measurements in which automated apparatus overestimated blood pressure in younger ages and mercury sphygmomanometer underestimated blood pressure in old ages, and in a few, the latter is higher than the other. This is in agreement with a study carried out by Menezes *et al.* (2010) who reported the digital device showed a high level of agreement with the mercury manometer when measuring systolic BP. The level of agreement was lower for diastolic BP, which is also confirmed by this present study. Hyun *et al*. (2015) stated that it is necessary to check the reliability of automatic blood pressure devices used in hospitals. In addition, an easier and more convenient protocol should be developed for routine calibration of automatic devices. While some studies clearly favour oscillometric devices (Myers, 2010), others argue that auscultatory measurements are comparatively more accurate (Myers *et al*., 2011). Compared with mercury sphygmomanometers, automated devices were generally thought to underestimate BP in crossover studies (Myers *et al.*, 2007).

The results on inter-arm differences found in this study is similar to those observed in a study by Arnnet *et al.* (2005), where the mean interarm diastolic and systolic BP differences were 2.96 ± 2.51 and 4.61 ± 4.10 mmHg, respectively. This also showed that most of the subjects used in this present study were healthy and were not predisposed to cardiovascular complications.

One limitation of this study was that the findings applied only to one type of automatic BP monitor, the OMRON M2 BASIC and cannot be generalized to other devices. Some automated devices may have better performance than OMRON M2 BASIC for intermittent measurements, even though data for direct comparison are not yet available.

Conclusion

This study emphasized on comparison of manual and automated apparatus using the same arm. It is known from this study that in checking for accuracy and suitability for diagnosis, the use of mercury sphygmomanometer which gave accurate readings for both SBP and DBP is of best use in taking blood pressure readings, in other to get an accurate reading. The findings implicated that the digital devices should be used with caution, doubt and suspicion.

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