Validation of an iCare Health Monitor smartphone application in the assessment of vital signs among stroke survivors in a poor-resource country

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Abstract

Background: Frequent and accurate monitoring of blood pressure (BP) is a vital part of stroke management. There is therefore the need for availability of simple, portable and accurate devices for monitoring BP at any point in time.

Objective: To determine the validity and reliability of the iCare Health Monitor (iCHM) smartphone application in the measurement of BP, heart rate (HR) and respiratory rate (RR) amongst stroke survivors in Anambra State.

Methods: This was a cross-sectional survey involving 86 stroke survivors (64.0% males; mean age = 65.23 ± 12.10 years) consecutively recruited from three conveniently selected centres in Anambra State. BP, PR and RR were assessed using both the standardised methods and iCHM. The parameters were reassessed with the iCHM after few minutes. Convergent validity and test-retest reliability of the iCHM were determined using Pearson product moment correlation and intra-class correlation coefficient respectively at an alpha level of 0.05.

Results: The convergent validity of the iCHM was excellent in measuring systolic BP (SBP) ($r = 0.96; p < 0.01$), diastolic BP (DBP) ($r = 0.93; p < 0.01$), HR ($r = 0.96; p < 0.01$) but moderate in measuring RR ($r = 0.74; p < 0.01$). The test-retest reliability of the iCHM was excellent in assessing SBP (ICC = 0.95; $p < 0.01$), DBP (ICC = 0.94; $p < 0.01$) and HR (ICC = 0.92; $p < 0.01$) but poor in assessing RR (ICC = 0.35; $p = 0.03$). Also, the iCHM displayed clinically insignificant bias.

Conclusion: The iCHM is a valid and reliable tool for assessing BP and HR (but not RR) among stroke survivors. Its use is therefore recommended especially in poor-resource countries where gadgets for assessing BP and PR might not easily be affordable and available.

Keywords

iCare Health Monitor, mobile application, stroke, assessment, validation, blood pressure, pulse rate, heart rate, respiratory rate

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Introduction

Stroke is a major cause of mortality and long-term disability, and imposes a heavy emotional and financial burden on the sufferers, families and societies.1–3 Though, the burden of stroke has reduced in high-income countries due to improved prevention, acute treatment and neurorehabilitation services, the menace of stroke has continued to rise in low-and-middle-income countries as a result of increased prevalence of modifiable risk factors in these countries.2,4

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Hence, the new millennium has seen increasing reports of a growth in the burden of stroke in Africa with a resultant increased clamour to address these risk factors.\textsuperscript{1–6} Hypertension is the single most important among these risk factors which can equally lead to stroke recurrence among stroke survivors.\textsuperscript{5,7} Consequently, prompt and appropriate assessment of blood pressure is very vital both pre- and post-stroke periods.

Constant monitoring of vital signs (especially blood pressure) is indispensable in both stroke prevention (primary and secondary) and rehabilitation.\textsuperscript{5,8,9} Abnormal blood pressure, heart rate (pulse rate) or even breathing rate can adversely affect the outcomes of stroke prevention and rehabilitation.\textsuperscript{9–11} Hence, frequent and efficient monitoring of vital signs (especially blood pressure) at different locations, and in all circumstances is of paramount importance during stroke rehabilitation. Though the auscultatory and the automated oscillometric sphygmomanometers are currently the gold standard in assessing blood pressure, the shortcomings of these techniques (including high sophistication, cumbersomeness, exorbitant cost and limited usage in every life circumstance and situation) have reduced their non-clinic usage among patients.\textsuperscript{12} This has led to the emergence of new technologies, including cuffless smartphone applications.\textsuperscript{12–14} Even though these smartphone applications may be less accurate than the gold standards, they are simple, easily accessible, portable and more convenient.\textsuperscript{12} These features of mobile applications have popularised mobile health (mHealth), which is the use of mobile applications for diagnosis, treatment or health management.\textsuperscript{15}

With the continuous increase in the global usage of smartphones, the popularity of the mHealth is increasing by the day. Over 70% of the world population own at least one smartphone.\textsuperscript{16} In Nigeria, over 80 million individuals (37.3% of the total population) are mobile internet users in 2022, with 25 to 40 million being smartphone users. The number of Nigerian smartphone users is forecast to grow to more than 140 million by 2025.\textsuperscript{17,18} This suggests that any effective heath package incorporated in mobile gadgets would likely record a tremendous utilisation.\textsuperscript{16} Considering the ease of accessibility of these applications, they can improve health outcomes especially in low-income countries where the standard diagnostic tools are scarce, but smartphones widely available.\textsuperscript{19} Hence, many mobile applications for assessing blood pressure and other aspects of health have been developed, and are easily available and downloadable from Google Play and Apple iTunes.\textsuperscript{12,20} However, these applications have questionable validities and reliabilities as none has documentation of validation against a gold standard.\textsuperscript{20} Validation of these applications would allow wide spread diagnosis and management of health conditions.\textsuperscript{13} The iCare Health Monitor is one of the mobile applications that assesses health parameters. It is arguably one of the most versatile of these applications as it assesses different health parameters including blood pressure, pulse and heart rates, respiratory rate, lung capacity, oxygen saturation and so on.\textsuperscript{21} However, the psychometric properties of the iCare Health Monitor in assessing these aforementioned health parameters had not been ascertained. The present study was therefore designed to assess the validity and reliability of the iCare Health Monitor on measuring blood pressure, heart rate and respiratory (breathing) rate among individuals with stroke in Anambra State, Nigeria. It was hypothesised that the iCare Health Monitor would be valid and reliable in assessing blood pressure, heart rate and respiratory (breathing) rate in this group.

**Methods**

**Design**

This was a cross-sectional survey involving consecutively recruited adult stroke survivors (18 years and above) who were met at the physiotherapy out-patient clinics, neurology clinics and medical wards of two purposively sampled public tertiary hospitals: Nnamdi Azikiwe University Teaching Hospital, Nnewi, Anambra State, and Chukwuemeka Odumegwu Ojukwu University Teaching Hospital Amaku, Awka, Anambra State. The two hospitals were the only public tertiary hospitals in the state, and were chosen because of their potential to yield high sample size. The protocol for the study was approved by the Ethics Committee of Nnamdi Azikiwe Teaching Hospital, Nnewi, Anambra State before commencement of data collection. The participants gave their written or verbal informed consent before their recruitment into the study. A sample size of 86 has an 85% power to detect a poor correlation coefficient of 0.31 at alpha level of 0.05. To avoid underestimating the sample size, a room was given for a possible poor correlation coefficients when the corresponding values from the two measurement methods were correlated. Sample size was calculated a priori using G* Power software (version 3.0.10), a globally utilised sample calculator.\textsuperscript{22,23} Data collection lasted for five months from February to June, 2018.

**Instruments**

1. **The iCare Health Monitor (version 2.8.5).** This is a non-copyrighted free android application that was downloaded at https://icare-health-monitor.en.softonic.com/android. The application works through the principles of photoplethysmography which involve the analysis of a photoelectric pulse wave signal detected at the skin surface.\textsuperscript{24}
2. **Samsung Galaxy S7.** This is a mobile phone with 6.0 Android operating system. The iCare Health Monitor was downloaded and installed on the mobile phone.
for use in automated assessment of blood pressure, heart rate and respiratory rate of the participants.

3. Stop Watch (Riken). This was used to assess participants’ heart rate.

4. Stethoscope (Ohrom Hem). This was used for manual assessment of blood pressure of the participants.

5. Mercury sphygmomanometer (Kriss Alloy). This was also used for manual assessment of blood pressure of the participants.

**Data collection**

The socio-demographic variables of the participants were recorded. The systolic and diastolic blood pressure of the participants were measured with the stethoscope and the sphygmomanometer using the conventional sphygmomanometry. Two readings were taken and the average recorded. The pulse (heart) and respiratory rates were recorded with the aid of the stopwatch using the conventional method of palpating the radial artery at the wrist of the unaffected arm of the stroke survivors and by counting the number of breathing cycles respectively. The measurement was done twice while the average was recorded. The iCare Health Monitor application was then opened on the phone. Each participant was encouraged to stay as quiet as possible. The mobile lens/ sensor was then gently covered with tip of the index finger of the participant with minimal pressure. The finger was kept on the sensor until the values were displayed on the mobile screen. The measurement was repeated and the average was recorded. The mobile monitoring procedure was repeated after 2 min. All measurements were made at the same time (a period of about 10 min) in order to avoid time bias in the values of blood pressure, pulse rate and respiratory rate.

**Data analysis**

Data obtained were analysed using the Statistical Package for Social Science (SPSS) version 21.0 (IBM Corp., Armonk, New York, USA). Participants’ demographic variables were summarised using frequency counts, percentages, range, mean and standard deviations. The data were assessed for normality using the Kolmogorov–Smirnov test. Pearson product moment correlation was used to estimate the level of correlation between the corresponding participants’ vital sign values measured using the iCare Health Monitor and the conventional methods (performed using sphygmomanometer, stethoscope and stopwatch). This was done to determine the convergent validity of the iCare Health Monitor. The correlation coefficients were interpreted as follows: \( r < 0.3 \) = poor correlation; \( 0.3 \leq r < 0.5 \) = slight correlation; \( 0.6 \leq r < 0.8 \) = moderate correlation, and \( r \geq 0.80 \) = excellent correlation. Independent \( t \)-test was used to test for significant differences in participants’ vital sign values measured using the two different methods.

The Bland-Altman plot was used to quantify the agreement in systolic blood pressure values assessed using the two methods. However, the plot was not used for the diastolic blood pressure, pulse rate, and respiratory rate as the data distribution violated the assumptions of the plot (which is normal distribution of the differences in the measured values from the two methods). The intraclass correlation coefficient (ICC) was used to assess the level of correlation between the two sets of average vital sign values measured by the iCare Health Monitor on the first and second (taken after 2 min) occasions in order to determine the test-retest reliability of the mobile application. The ICC values were interpreted thus: \( < 0.4 = \) low reliability; \( 0.4 \leq \text{ICC} < 0.75 \) = moderate reliability; \( \text{ICC} \geq 0.75 \) = excellent reliability. The alpha level was set at 0.05

**Results**

Eight-six (86) adult stroke survivors (64.0% males) with mean age of 65.23 ± 12.10 years participated in the present study. One-quarter (25.6%) of the participants were unemployed whereas 53.5% were married. The average post-stroke duration of the participants was 41.56 ± 34.71 months (Table 1).

The mean systolic and diastolic blood pressure, pulse (heart) rate and respiratory rate values as measured using the conventional and the mobile application methods are displayed in Table 2. There was no significant difference between the corresponding values of systolic blood pressure \((t = -0.22; p = 0.83)\), diastolic blood pressure \((t = 0.54; p = 0.59)\) and pulse rate \((t = 0.00; p = 1.00)\) as measured by the conventional and the mobile application methods. However, there was significant difference in respiratory rate between the two methods of measurement \((t = -3.22; p < 0.01)\).

There was excellent significant relationship between the corresponding values of participants’ systolic blood pressure \((r = 0.96; p < 0.01)\), diastolic blood pressure \((r = 0.93; p < 0.01)\) and pulse rate \((r = 0.96; p < 0.01)\) measured through the conventional and the mobile application approaches. The correlation between the respiratory rate \((r = 0.74; p < 0.01)\) assessed using the two methods was moderate (Table 3). The Bland-Altman plot showed the mean bias in the systolic blood pressure between the conventional sphygmomanometry and the iCare Health Monitor Method as \(-0.32 \pm 4.3521 \text{ mmHg}\), and the limits of agreement were \(-8.8501 \text{ and } 8.2101 \text{ mmHg}\) (Figure 1).

There was excellent correlation between each of systolic blood pressure \((\text{ICC} = 0.95; p < 0.01)\), diastolic blood pressure \((\text{ICC} = 0.94; p < 0.01)\) and pulse rate \((\text{ICC} = 0.92; p < 0.01)\) measured using the mobile application method at two different occasions, indicating evidence of test-retest reliability of the mobile application method. However, the mobile application displayed weak test-retest reliability with respiratory rate \((\text{ICC} = 0.35; p = 0.03)\) (Table 4).
Discussion

This study was aimed at determining the validity and reliability of the iCare Health Monitor smartphone application in the measurement of vital signs (heart rate, respiratory rate and blood pressure) amongst stroke survivors in selected hospitals in Anambra State, Nigeria. Majority of the participants were males. Being a hospital-based study, the lower proportion of women in this study might be attributed to the reported difficulties faced by women in accessing healthcare in the setting of this study.30 These difficulties could stem from gender inequalities and financial marginalisation of women especially in rural communities.31 The mean age of participants in the present study fell within the range for older adults. This may not be surprising as the risks of stroke increase with age.32

The lack of significant difference, and the presence of excellent correlation between the corresponding blood pressure and pulse (heart) rate values measured with the conventional sphygmomanometry and the iCare Health Monitor application demonstrates that the iCare Health Monitor can determine blood pressure and pulse rate in stroke survivors with an accuracy that is comparable to the current gold standards. The iCare Health Monitor also

| Variable         | Class      | Frequency | Percentage | Range | Mean ± SD |
|------------------|------------|-----------|------------|-------|-----------|
| Gender           | Male       | 55        | 64.0       | -     | -         |
|                  | Female     | 31        | 36.0       | -     | -         |
| Occupational status | Unemployed | 22        | 25.6       | -     | -         |
|                  | Farmers    | 13        | 15.1       | -     | -         |
|                  | Traders    | 21        | 24.4       | -     | -         |
|                  | Civil servants | 18  | 20.9       | -     | -         |
|                  | Artisans   | 12        | 14.0       | -     | -         |
| Marital status   | Single     | 7         | 8.1        |       |           |
|                  | Married    | 46        | 53.5       |       |           |
|                  | Divorce    | 10        | 11.6       |       |           |
|                  | Widowed    | 22        | 25.6       |       |           |
| Age (years)      |            |           | 40–94      | 65.23 ± 12.10 |
| Post-stroke (months) |        |           | 1–123     | 41.56 ± 34.71 |

Table 2. Independent t-test comparing the mean blood pressure, pulse rate and respiratory rate values measured using the conventional manual methods and the iCare Health Monitor application.

| Variables                               | Mean ± SD Manual method | iCare ± SD | T     | p     |
|-----------------------------------------|-------------------------|------------|-------|-------|
| Systolic blood pressure (mmHg)          | 153.37 ± 15.50          | 153.88 ± 14.77 | 0.22  | 0.83  |
| Diastolic blood pressure (mmHg)         | 77.24 ± 7.89            | 76.60 ± 7.63 | 0.54  | 0.59  |
| Pulse rate (beats/min)                  | 73.86 ± 7.74            | 73.86 ± 7.68 | 0.00  | 1.00  |
| Respiratory rate (cycles/min)           | 23.28 ± 1.91            | 24.19 ± 1.81 | −3.22 | <0.01* |

*Significant at p < 0.05.
demonstrated excellent test-retest reliability in assessing systolic blood pressure, diastolic blood pressure and pulse rate but poor test-retest reliability in assessing respiratory rate of the participants. This gives evidence of reproducibility of the application in assessing blood pressure and pulse rate among stroke survivors. The present results will be very valuable to stroke survivors, who usually require frequent monitoring of their blood pressure, but still may not easily use other available methods due to sophistication, unavailability and inconvenience. With the wide spread of smartphone usage even in low-income countries, this application can improve diagnosis and management of abnormal blood pressure and heart rates in these countries. Going by the moderate correlation and the significant difference recorded between the two methods of assessment, present results therefore discourages the use of the iCare Health Monitor in assessing respiratory rate among stroke survivors.

Considering the observed limit of agreement (−8.8501 and 8.2101 mmHg) in this study, the iCare Health Monitor application would not overestimate or underestimate the systolic blood pressure with a value of up to 10 mmHg. A difference of less than 10 mmHg in systolic blood pressure has been severally reported to be clinically insignificant. This, thus, buttresses the fact that the iCare Health Monitor can fairly estimate an individual’s systolic blood pressure with a negligible bias.

Table 3. Pearson product moment correlation showing the relationships between blood pressure, pulse rate and respiratory rate values measured using the conventional manual methods and the iCare Health Monitor application.

| Scores            | R    | p       |
|-------------------|------|---------|
| Systolic blood pressure | 0.96 | <0.01*  |
| Diastolic blood pressure | 0.93 | <0.01*  |
| Pulse rate        | 0.96 | <0.01*  |
| Respiratory       | 0.74 | <0.01*  |

*Significant at $p < 0.05$.

Figure 1. Bland-Altman plot showing the plot of differences in the systolic blood pressure between conventional sphygmomanometry and iCare Health Monitor method.
This study is not without limitations. Though the sample size of this study was adequate, a bigger sample size would have improved the external validity of the study. Also, this study did not explore the effectiveness of the iCare Health Monitor in stroke survivors with different blood pressure levels (hypotensive, normotensive and hypertensive individuals). Thus, an important next step is to recruit individuals with different blood pressure statuses. Additionally, the present study was restricted to stroke survivors, and might not be easily generalised to general population. Future studies are needed to ascertain the effectiveness of the application in the general population.

Conclusion

The iCare Health Monitor application is a valid and reliable tool for assessing blood pressure and pulse rate among stroke survivors. However, it displayed questionable validity and reliability in assessing respiratory rate in this group. Considering its simplicity, affordability, portability, convenience, and acceptable psychometric properties, its use in the assessment of blood pressure and pulse rate (but not respiratory rate) among stroke survivors is encouraged.

Contributorship: EC, IU and LC researched literature and conceived the study. UG, UP, MJ and LC were involved in protocol development, gaining ethical approval and data collection. EC performed data analysis, and wrote the first draft of the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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Table 4. Intraclass correlation coefficient showing the relationships between corresponding scores of blood pressure, pulse rate and respiratory rate values measured using the mobile application method at two occasions.

| Scores                  | ICC  | p       |
|-------------------------|------|---------|
| Systolic blood pressure | 0.95 | <0.01*  |
| Diastolic blood pressure| 0.94 | <0.01*  |
| Pulse rate              | 0.92 | <0.01*  |
| Respiratory             | 0.35 | 0.03*   |

*Significant at p < 0.05.

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