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A mHealth-based Care Model for Improving Hypertension Control in Stroke Survivors: Pilot RCT

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Abstract

Purpose—Hypertension (HTN) is significantly under-treated in stroke survivors.

We examined usability and efficacy of a mHealth -based care model for improving post-stroke HTN control (Funding: AHRQ R21HS021794).

Methods—We used a RCT design. Planned study duration was 90 days. Intervention arm (IA) participants measured their BP daily using a smart phone and wireless BP monitor. This was transmitted automatically to the study database. Investigators (Physician + PharmD) made bi-weekly medication adjustments to achieve the BP goal. Control arm (CA) participants received a digital BP monitor and usual care. We examined Usability (measured with Marshfield System Usability Survey) and HTN control efficacy using an ITT (intent-to-treat) and as-treated (AT) analyses.

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CONFLICTS OF INTEREST

None

DISCLOSURES

KL serves on the adverse events committee for Abbott (St. Jude Medical).

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Results—Fifty participants (IA=28; CA = 22) completed the study. The Marshfield survey question, “I thought the system was easy to use” mean score was 4.6, (5 = strongly agree). Mean SBP declined significantly between enrollment and study completion in the IA. In ITT, IA SBP declined 9.88 mm, $p=0.005$. In AT, IA SBP declined 10.81 mm, $p=0.0036$. CA SBP decline was 5–6 mm Hg (not significant). In the ITT, baseline HTN control (SBP < 140 mm Hg) was 50% in IA and CA. At study completion, HTN was controlled in 82% (23/28) of IA and 64% (14/22) of CA ($p = 0.14$). In the AT, HTN was controlled in 89% (23/26) of IA and 58% (14/24) of CA, ($p=0.015$).

Conclusion—A mHealth-based HTN care model had excellent usability and provided better HTN control than usual care in stroke survivors.

Keywords

mHealth; Stroke survivors; Hypertension; Self-management

INTRODUCTION

Background

The 2014 American Heart/Stroke Association Guidelines state that, *the treatment of hypertension is possibly the most important intervention for the prevention of stroke*.^{1,2} Unfortunately, there is sub-optimal management of vascular risk factors in the outpatient setting and medication non-compliance by stroke survivors.³ A large population based study showed that 51% of stroke survivors had elevated blood pressure (BP) one year post-stroke with 19% having severe elevations (BP 160/95).⁴

Self-measured blood pressure monitoring (SMBP) can be useful in improving hypertension (HTN) control. A meta-analysis found that SMBP lowered blood pressure (BP) compared to usual care without self-monitoring.⁵ Consequently, SMBP is recommended by the AHA guidelines and JNC-7 as an adjunct to improve HTN control.^{1,2,6,7} An AHA Statement on the Use of Mobile Devices for CVD prevention found that mHealth (mobile health technology) can facilitate SMBP and thereby improve HTN control.⁶ The review found that while mHealth showed efficacy in reducing BP in hypertensive patients in idealized controlled settings, there were significant evidence gaps for effectiveness in a real-world settings. A key question was whether mHealth facilitated HTN management was generalizable to a broader consumer base including the elderly and disabled such as those with stroke?⁶ Herein, we present the results of a pilot study (funding: AHRQ R21 HS021794) that examines this question. Our pilot study examines usability, feasibility and efficacy of mHealth, in facilitating HTN self-management in stroke survivors and calculates sample sizes for a larger trial.

Our intervention was informed by a review of cell phone technology based healthcare interventions,⁸ the literature on telehealth and remote monitoring,^{9,10} as well as a focus group of stroke survivors and care givers. The focus group recruited from our local stroke support group was convened in 2012 to test smart phones, tablet devices (iPads) and wireless BP monitors. Focus group participants answered questions regarding their comfort with technology and use of home BP monitoring devices. We learned the following: 1)

participants had a preference for smart phones over iPads despite the larger screens of iPads; 2) 75% of them had used a digital home BP device and 50% of them continued to do that, though not consistently; and 3) there were no significant barriers to home BP self-monitoring. The focus group informed our choice of mobile technology for this study.

Objective

We describe the results of a pilot, proof-of-concept study to demonstrate that stroke survivors are able to use mHealth technology to improve HTN management. Our goals with this study were to evaluate the strengths and weakness of wireless technology and identify barriers to their use in stroke survivors, understand patient experience and acceptance of this technology mediated model of care, and estimate the effect sizes for a larger trial.

METHODS

Design

Study design was a randomized controlled trial (RCT) design with 2 parallel arms with 1:1 allocation. This was an exploratory, pilot study and lasted from 2012–2016.

Intervention

The intervention was mHealth based HTN management. The multi-level intervention had 3 components including i) patient education delivered by a nurse coordinator, ii) SMBP, iii) rapid availability of BP to an inter-professional care team and responsive medication adjustment and feedback.

Intervention participants were educated on the importance of HTN management after stroke. They were provided with a smart phone and an upper arm, Withings (Nokia) wireless BP monitor. This monitor is clinically validated and FDA approved.¹¹ Participants were trained on using the wireless equipment for SMBP and expected to self-monitor their BP daily. Participants were instructed to measure their BP prior to breakfast, coffee or medications. The smart phone transmitted their daily BP automatically to a database. Study investigators (KL, SW, a physician and pharmacist) reviewed BP weekly and adjusted anti-hypertensive medications typically biweekly as needed to reach BP goal. Study investigators used 7-day moving averages of daily BP to make decisions on medication adjustments. If a patient measured BP multiple times during the day, the earliest set of BP measurements for the day was used. We examined all the BP within a 20 minutes window starting with the first BP of the day, and, then used the last BP in that 20 minute window as the BP used for decision making. Patients were instructed on proper, standard techniques for BP measurement. HTN was managed according to the AHA and JNC guideline recommendations with PCP (primary care provider) input.^{7,12} Communication with PCP was facilitated via the EMR (Electronic Medical Record) and medication changes were documented in the EMR. If the patient was already on anti-hypertensive medications, we adjusted existing medication dosage and added new medications as needed. We communicated with patients regarding medication changes via phone with two patients preferring email communication, which we provided.

Control

Each control participant received: 1) education on the importance of HTN control; 2) advice to self-monitor BP daily and share with PCP at clinic visits; and 3) encouragement to follow up with PCP based on follow-up schedule advised by PCP. Control participants were given an Omron digital BP monitor and taught how to use it. This monitor has been clinically validated and is FDA approved.¹³ The control monitor did not transmit BP unlike the intervention monitor.

Our goal was to operationalize the current state of clinical care and minimize variation in order to have consistent delivery of the comparison condition. Many providers educate patients on HTN control. We standardize this by delivering the same HTN education to all participants. In our focus group, we found that many patients had a home digital monitor but did not use it consistently. We standardized this by giving control participants a digital monitor and educating them on its use.

Study duration

Participants were followed for 90 days. When HTN control could not be achieved in some of the intervention participants within 90 days, we went back to the IRB to obtain permission for extended monitoring up to 6 months.

Participants

Participant recruitment took place on the inpatient acute stroke unit as well as on the acute rehabilitation unit. Included were acute stroke survivors aged 40–85 years, with a neurologist validated ischemic stroke or intra-parenchymal hemorrhage. Participants had to be able to communicate in English, able to use or learn to use the wireless equipment and smart phone, answer survey questions and, have either a new diagnosis or history of HTN. Participants were excluded if they were unable to give consent or complete the required trial tasks. Initially, we did not exclude co-morbid conditions. But over the course of the trial, based on our experience with the complexity of managing HTN in patients on dialysis, we excluded participants with end stage renal disease.

Data / Outcomes

Outcomes of interest were primarily usability and feasibility of mHealth technology for HTN control in stroke survivors and the rates of HTN control into guideline based ranges. Usability was measured at the end of the study in intervention participants by using the Marshfield Usability Survey.¹⁴ This survey is based on a Likert scale (1=Strongly disagree; 2 = Disagree; 3=Neither agree or disagree; 4=Agree; 5=Strongly agree). Feasibility or usage was measured by the number of days BP was transmitted by intervention participants. Efficacy of HTN control was examined in two ways. First, we operationalized HTN control as SBP below guideline threshold of < 140 mm Hg measured at study end. Second, we examined the average systolic BP (SBP) at study enrollment and end in the intervention and control groups. The study coordinator measured BP with the same monitor for all participants at the exit interview. Finally, we asked participants for unstructured feedback on the technology as well as the mHealth based HTN care model and if they had suggestions for changes for a larger study. We also documented technical difficulties reported by

participants. Finally, medication adherence at study end was measured using the validated modified Morisky scale, which measures adherence intention in terms of motivation and knowledge.¹⁵

Sample Size

This was a pilot study intended to study barriers and patient acceptance. We wanted to assess the effect size in order to design a larger study and targeted a sample size between 50–60 participants to provide preliminary data.

Randomization, Allocation, Blinding

Block randomization methods were implemented within an automated online randomization tool (RedCAP).¹⁶ Block sizes and randomization schemes were determined by a data analyst who was not involved in patient recruitment. The online randomization tool was accessed by study recruiters after the participant expressed interest in the study and treatment was assigned by RedCAP. After treatment group assignment, the PI (physician) and the pharmacist were not blinded since they had to perform the medication adjustment. Allocation was 1:1 to intervention and control.

Ethics and Informed Consent

This study was approved by the Institutional Review Board (IRB) of the University of Minnesota (Study ID: 1212m25581). Informed consent was obtained in person. Stroke survivors are potentially a vulnerable group due to varying degrees of post-stroke disability. We therefore confirmed that the participants understood the purpose of the trial and what was required of them during the informed consent process. All patients were capable of consenting for themselves though frequently care givers were present during the consent process. This trial is a comparison of care delivery models with the intervention group getting a more intense management of their HTN facilitated by mobile technology. While the control group also received a BP monitor and education on the importance and techniques of measuring BP, they did not receive the responsive feedback and medication adjustment that the intervention group did. We wanted to avoid change in control participant behavior based on the intervention condition (contamination of the control). Hence, we obtained IRB permission for separate consent forms for the two study arms. At the end of the study a debrief letter was sent to all the participants explaining the intervention and control conditions and reiterating that data will be reported in an aggregate with no identifiers and offering participants the option of withdrawing their data. None of the participants withdrew their data.

No support, sponsorship or compensation was provided by Apple, Withings/Nokia or Omron. Verizon provided the study iPhones with the data plan for a reduced charge for study participants.

Statistical Analysis

We examined mHealth system usability by measures of centrality (mean, median) Marshfield Usability Scale questions. System feasibility was analyzed as the percentage of days BP was transmitted compared to days BP monitoring was done. We performed an

intent-to-treat analysis as well as an as-treated analysis for the end-point of HTN control. We compared the percentage of subjects at goal BP between the two groups using the chi-square test of proportions. We also constructed 2×2 contingency tables for each study arm to test for marginal homogeneity (McNemar's test). This test compares proportions of participants at goal BP at enrollment vs. study completion for each arm separately. We compared mean pre vs. post SBP in the intervention and control groups using the paired T-Test (within group test). We also analyzed the mean SBP reduction between the intervention and control groups using a 2-sample t-test (between-group). We used the observed effect size for HTN control to calculate the sample size for a larger study. Medication adherence was compared between the two groups by comparing mean scores on Motivation and Knowledge sub-domains using the 2-sample T-Test.

RESULTS

A total of 56 participants were randomized. There were 34 intervention and 22 control participants (CONSORT Figure 1). Of these, 6 intervention participants were withdrawn for reasons shown in Appendix Table I. Two intervention participants crossed over into the control arm, (reasons in Figure 1). Of the total 50 patients in the study (excluding 6 withdrawals), 26 intervention patients and 24 control patients completed the study.

Table 1 describes participant demographics. Mean intervention participant age was 63.1 years, (SD 9.7, range 42–81 years). Mean control participant age was 68.3 years, (SD 10.0, age range 46–85 years). Post-stroke disability as measured by median Modified Rankin Score, was 2 or less across all groups (slight disability).¹⁷

mHealth feasibility in stroke survivors

Intervention participants transmitted BP data for an average of 89% of days under monitoring and, 92% of subjects transmitted their BP for more than half the monitored days (Table 2). Most participants had their HTN controlled within 90 days (19/26). Some participants needed more than 90 days for HTN control (7/26). We extended their monitoring period (with IRB approval) up until 6 months and monitored them until HTN control was achieved or if it was felt that the control could not be achieved by remote monitoring. Some survivors have continued daily BP measurement after the study ended stating that it has become a part of their daily routine.

mHealth usability in stroke survivors

The Marshfield Usability Survey results (Table 3) indicate that stroke survivors were highly satisfied with the mHealth system, ("In general I was satisfied with the system" mean score = 4.6, median =5). They found it easy to use, ("It was easy to learn to use the system", mean score = 4.5, median = 5). The participants felt that they could be more involved in their health care using mHealth, ("I could be more involved in my care by using the system, ("mean score = 4.1, median=4). Since the participants were stroke survivors, a key question was whether they needed assistance with the system. The survey indicated that they did not, ("I felt that I needed someone's help to be able to use the system, (mean score=2.3,

median=2). Other salient findings were that the participants felt that their privacy was well protected, and, they could always trust the system to work, (Table 3).

mHealth efficacy for HTN Control

Intent-to-treat analysis—The intervention group denominator included 28 participants, including the two participants who crossed over to the control condition. The control group denominator included 22 participants. In the intervention arm, 50% (14/28) participants had their HTN controlled at enrollment and 82% (23/28) had their HTN controlled at study completion. In the control arm, 50% (11/22) had their HTN controlled at enrollment and 64% (14/22) had their HTN controlled at study completion (chi-square $p = 0.14$), Table 4. The McNemar test was significant for the intervention arm (chi-square=7.11, $p=0.0077$) but not for the control arm, (chi-square=0.44, $p=0.51$). The two cross-over patients analyzed as part of the intervention were not controlled at study end.

In the paired T-Test (within group test), the mean decline in SBP (baseline vs. study end) for the intervention arm was 9.88 mm Hg (95% CI: 3.17, 16.40) and significant, $p=0.005$. For the control arm, the mean decline in SBP was 5.91 mm Hg (95% CI: -1.57, 13.38) and not significant, $p=0.12$. When we compared these mean changes between groups (-9.8 vs. -5.9; 2-sample t-test), the results were not significant, ($p=0.4$). When we examined the BP changes in participants uncontrolled at baseline, the BP changes were exaggerated in both intervention, (-19 mm Hg SBP), and, control (-16 mm Hg SBP) arms, but did not reach significance.

Medication adherence scores were similar between the two groups. Three control participants and one intervention participant did not answer the medication compliance questionnaire. Mean motivation score for intervention arm was 2.3 (SD 0.8, $n=27$), and for the control arm was 2.6 (SD 0.8), ($p=0.3$, $n=19$). Mean knowledge score for intervention arm was 2.9 (SD 0.4), and for the control arm thus was 2.8 (SD 0.5), ($p=0.9$).

As treated analysis—In the intervention arm, 54% (14/26) participants had their HTN controlled at enrollment and 89% (23/26) had their HTN controlled at study completion. In the control arm, 46% (11/24) had their HTN controlled at enrollment and 58% (14/24) had their HTN controlled at study completion (chi-square $p = 0.015$), Table 4. The McNemar test was significant for the intervention arm (chi-square=7.11, $p=0.0077$) but not for the control arm, (chi-square=0.44, $p=0.51$). These results are similar to the intent-to-treat analysis.

In the paired T-Test (within group), the mean decline in SBP for the intervention arm was 10.81 mm Hg (95% CI: 3.86, 17.76) and significant, $p=0.0036$. For the control arm, the mean decline in SBP was 5.13 mm Hg (95% CI: -1.82, 12.07) and not significant, $p=0.14$. When we compared mean changes between groups (-10.8 vs. -5.1; 2-sample t-test), the results were not significant, ($p=0.2$). When we examined the BP changes in participants uncontrolled at baseline, the BP changes were exaggerated in both intervention, (-23 mm Hg SBP), and, control (-13 mm Hg SBP), arms, but did not reach significance.

Medication adherence scores were similar between the two groups. Mean motivation score for intervention arm was 2.4 (SD 0.8, $n=25$), and for the control arm was 2.5 (SD 0.9, $n=21$),

($p=0.51$). Mean knowledge score for intervention arm was 2.9 (SD 0.4), and for the control arm thus was 2.8 (SD 0.4), ($p=0.57$).

An illustrative BP trajectory in a participant's whose HTN was controlled is shown in Figure 2. Three participants in the intervention condition did not have their HTN controlled at the end of the study. One participant, under extended monitoring for 107 days, was resistant to medications adjustments or addition despite primary care involvement and advice. One participant had difficulty using the monitor, despite training and observation at enrollment. He transmitted data for 78 days. One person, the longest monitored at 177 days, had fluctuating BP and HTN control was established intermittently but not for a sustained period of 2 weeks. Hence, we referred him back to primary care for possible ambulatory BP monitoring.

Unstructured feedback on technical issues, positive and negative feedback—

Twenty five (of 26) intervention participants provided unstructured feedback. Common technical feedback (Appendix Table II) was that the phone charge ran out if not plugged in or monitor battery lost charge ($n=4$), having to play around with the phone to get the app to come up ($n=6$), wanting easier access to historic BP trends ($n=2$). There were no problems with cellular network access except for one participant who took the equipment with him when he went hunting, ($n=1$). There were no privacy breaches. Among intervention participants who withdrew study start, one person complained of the cuff pinching their triceps skin fold, (Appendix Table I).

Overall unstructured feedback was positive, (Appendix Table III). The most common positive feedback was that participants liked being “aware” of their BP, “knowing” or “keeping an eye” on their BP ($n=12$). Many participants liked the “automatic transmission” of BP sent directly to the MD ($n=11$). A negative comment was that participants did not like measuring their BP daily, ($n=4$), but would consider doing several times a week. One participant said that they would be willing to measure BP daily for 60 days but not for 90 days as requested by the study.

Participants also identified the different aspects of training which could be improved or added for a larger trial, (Appendix Table III).

DISCUSSION

Principal Results

To our knowledge, this is the first study using mHealth for improving HTN management in stroke survivors. We showed excellent usability and very high feasibility of this technology and care model in this population. The rates of self-monitoring and daily transmission were very high. This may reflect the fact that this is a population with a significant health condition and hence, likely to be highly motivated. The rate of HTN control was significantly higher in the mHealth group compared to the usual care control group in the as treated analysis (89% vs. 58%). While there was a substantial difference in the intent-to-treat analysis (82% vs. 64% HTN control at study end), this comparison was under-powered. A sample size of 135–150 / treatment arm would detect a 15% difference in the intent-to-treat

analysis with 80% power and a type I error rate (alpha) of 0.05. This sample size will need to be increased for any anticipated attrition. Since this is a pilot study, the effect estimates will inform a larger trial. Furthermore, while our study shows estimated efficacy of the intervention, there is need for demonstrating the clinical effectiveness of this technology on a larger scale within health systems, in populations including both stroke survivors as well as primary care patients who have not yet had a stroke, but, have uncontrolled HTN and hence, are at high risk of stroke and cardiovascular events. One question is whether the BP reductions were clinically meaningful. In the treatment arm, as-treated analysis, mean SBP/DBP (systolic/diastolic) reduction was 11/7 mm Hg and, intent-to-treat analysis, mean SBP/DBP reduction was 10/6 mm Hg. In the control arm, as-treated analysis, mean SBP/DBP reduction was 5/2 mm Hg and, intent-to-treat analysis, mean SBP/DBP reduction was 6/3 mm Hg. While there is a substantial BP difference between the two arms, the difference would likely increase if the study only included patients with uncontrolled hypertension as described in the Results and if we could minimize cross-over and drop out from the intervention arm. We included all stroke survivors with hypertension and at start of the study roughly half the patients already had their blood pressures controlled. Hence, one lesson is that this technology may be most useful in patients with uncontrolled HTN. Future trials should focus on understanding and mitigating patient cross-over and drop out.

Some of the lessons learned on this pilot study include clarification on appropriate exclusions especially in trials involving stroke survivors. For example, those with large vessel occlusions should be excluded from trials of protocol based HTN management. We also realized that the intervention was quite labor intensive since the investigators (KL and SW) discussed BP trajectories weekly and made medication adjustments biweekly. Translation of this study to a larger scale will require that providers be alerted only when BP exceeds pre-set parameters. These parameters would likely be guideline based thresholds.

Of note, we had excellent partnerships with primary care providers. They were very supportive of having their patients participate in the trial and appreciated the extra assistance in HTN management. Frequently, they reinforced the investigators messages regarding the need for medication adherence to the participants. One key aspect of our relationship with providers is that we did not stop any of the existing anti-hypertensive medications already added by the providers. Instead we made dose adjustments and added new medications as needed. We informed providers in advance of medication changes through the electronic medical record. Interestingly, there was no significant difference in medication adherence measures between the two arms. The improvement in BP control was most likely due to responsive medication adjustment by study investigators, though we acknowledge that we did not collect data on number of medication changes during the study period.

Strengths and limitations

Our participant population was elderly stroke survivors and this population is frequently left out of technology trials. Hence, our trial addresses an understudied group. Another strength of our study, despite it being a pilot project, is that participants were randomized to study arms. Hence, we have a comparison to a concomitant usual care control group. We acknowledge imbalance between the two treatment arms, (Table 1). More participants were

randomized into the intervention arm. There was no stratification of randomization based on prior experience with home BP monitoring or BP control at baseline. Intervention participants were younger and appeared to be better educated than the control participants. These imbalances in both the numbers and characteristics of participants in the two arms, likely due to the small sample randomized, may have influenced our final outcome. Nevertheless, we note that at baseline both groups had the same rates of HTN control (~50%). Furthermore our statistical analyses include the McNemar test and this takes into account rates of HTN control at enrollment. We also note that all withdrawals were from the intervention, (reasons in Appendix Table I). The control condition was usual care and did not require an active involvement by the patient. Hence, they did not have a reason to withdraw. One limitation is that we only followed participants for about 3–6 months. Hence, we could not evaluate whether the improved HTN control in the intervention group would be sustained over the long-term. A different limitation is that we extended monitoring for seven participants in the intervention. Of these seven, five were controlled during the extension and two could not be controlled. The reason for this extension is that while patients were participating and transmitting data, we felt that we could not stop medication management ethically. We acknowledge that we do not know the history of control participants beyond 90 days. These limitations are due to the pilot nature of the study. Our goal was to understand the problem of using self-management and mHealth and also to generate data to support a more sustained intervention within the health system. A larger, longer duration study with more people randomized will balance out participant characteristics and provide a more definitive answer.

Comparison to other work in this area

The intervention in our study while delivered using mHealth is actually a multi-level intervention with separate components some of which are independent of the technology. These components include: i) Education on the importance of HTN management control delivered by a nurse coordinator who also educated participants on the techniques for measuring BP correctly; ii) mobile technology to facilitate self-measured BP monitoring (SMBP); iii) Prompt feedback and responsive adjustment of medications by a provider team which comprised of a pharmacist and a physician. Each of these components including the SMBP and the responsive medication adjustment can be done without mHealth but the mobile technology makes this feasible and efficient. Guidelines including the JNC and the AHA concur that SMBP is beneficial to the management of HTN and promote it as a strategy to evaluate response to treatment and as an adjunct treatment in HTN management. mHealth makes SMBP feasible and within reach of a broad range of patients due to the penetration of mobile technology into the consumer population.

A natural comparison to mHealth mediated HTN management is Telehealth or telephone mediated systems for HTN management which have been implemented to varying degree within health systems.^{9,10,18} Telehealth systems for HTN management depend on telephone modem technology and require health systems to contract for telemonitoring services from a vendor. Our system is in contrast based on mobile technology and uses the patient's own smart phone. A free app allows the wireless monitor to interface with the smart phone. The app transmits the data to an online database. The database is free and there is no patient

service contract. Hence, mHealth mediated HTN management is more nimble and represents the next generation in technology.

A recent AHA scientific statement reviewed the literature on use of mHealth to improve HTN control.⁶ The statement found 13 RCT which examined use of an electronic platform (not necessarily smart phones) typically in the context of SMBP or supportive services to improve HTN management. None of them targeted stroke survivors. The AHA statement found that 9/13 trials showed promising efficacy for technology in BP reduction. Studies which showed a significant mean BP reduction had a combination of intervention strategies including patient educational resources, timely delivery of BP data to providers and personalized messages to patients. Our study intervention has all of these three components, and, as we stated earlier the mobile technology, the electronic medical record and supportive primary care providers facilitated easy intervention delivery. We compared our use of technology including self-monitoring, automated transmission without need for patient BP data upload, and responsive provider driven medication management with the 13 RCT listed in the AHA statement. We found that 10/13 had some element of SMBP with home BP monitors,^{18–27} only 4/13 had automated BP transmission. Of these, two were using modem based upload^{25,27} and two had Bluetooth technology.^{18,23} Furthermore, 6/13 had responsive provider driven anti-hypertensive medication management^{18–21,26,27} and an additional 2/13 had medication management in office visits where SMBP data was used^{22,23}. The low numbers of trials with automated transmission reflects the earlier time frame of these studies with many of them reported between 2008 and 2013. One interesting fact is that many of the RCT testing web-based, telehealth or mobile technology interventions were based outside the U.S. and, target patient populations were selected from primary care practices in most trials.^{18,20–24,28–30} Exceptions were the use of renal disease populations.^{27,31}

One conclusion from the AHA statement was that while many studies showed improved HTN control, there were still unanswered questions including whether this technology mediated approach to HTN management was sustainable over the long-term and whether it could be generalizable to a broader consumer base including elderly and those with disabilities such as stroke. Our pilot RCT addresses the second gap since it engages the population of stroke survivors who are typically elderly. We acknowledge that the participants we recruited had to be able to learn the use of mobile technology as a condition of study entry. They were stroke survivors who were discharged home after hospitalization or after acute rehabilitation and hence had a good outcome after stroke.

CONCLUSIONS

Our study shows excellent usability and feasibility of a mHealth system for HTN management after stroke. There was significant improvement in HTN control rates among participants who used the mHealth system compared to usual care controls. Our results call for a larger health system based trial in order to establish the long-term effectiveness of this approach for self-care of vascular risk factors and HTN management among high risk groups.

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APPENDIX

APPENDIX TABLE I.

Reasons for participant withdrawal from study

Reason for withdrawal	N	Withdrawn by	Comment
Was on dialysis; BP was too complex to manage due to changes in dialysate	1	Investigator	This was an early patient; Patients on dialysis and other complex medical conditions excluded going forward
Died soon after randomization before medication adjustment was started	1	Investigator	Death was likely sudden cardiac death and not related to study.
Had large vessel (carotid) occlusion and BP management was very gentle consequently	1	Investigator	BP was controlled and was a success for trial outcome. However, patient received extra attention due to medical complexity; hence not included in analysis; going forward we excluded participants with carotid occlusion
Felt overwhelmed after stroke; withdrew after randomization but before starting the study	1	Participant	
Felt cuff was pinching her arm; withdrew after randomization but before starting the study	1	Participant	None of the other patients complained about the cuff
Tripped on furniture while walking in the dark and was hospitalized for many weeks with subdural. Hospitalization not related to study. Tripped before medication adjustment was started.	1	Investigator	Study criteria was that patient would be withdrawn from study if they were not able to transmit for more than 2 weeks.

APPENDIX TABLE II.

Technical issues reported as part of unstructured feedback.

ID	Technology specific difficulties
2	Iphone charge ran out if not plugged in.
3	At times I was frustrated with iphone, I could not always get it to transmit
4	Looking at historical trends in BP is difficult though app has this software.
7	Sometimes phone needed back up / charging.
9	The cuff was sometimes difficult to put on my left arm. I could put it on my R arm.
14	One barrier was when battery ran out.
15	My wife had to help when the correct screen did not come up. I had no previous experience with the smart phone.
16	Sometimes the main screen did not show up right away. Need a timing device or reminder beep to tell you that it is time to take BP.
17	Once in a while I had to monkey around with the app to get the correct screen up.

ID	Technology specific difficulties
18	I had to play with the iphone to get the correct screen up. Coordinator showed me but I forgot.
23	Phone starts to lose charge. Had to keep re-charging. Had his own BP cuff and the study BP cuff and his own cuff did not always agree.
24	Sometimes App would not come up on the phone. Not familiar with Apple.
27	I took it when I went hunting but there was no cell service there.
34	I don't like the iphone.
36	Would have liked a larger screen.
38	Sometimes I had to play around with the phone when it did not get a reading. Initially I was not sure that the readings were going through until study PI called me.
40	Want to access average values, charts on BP trends more readily.

APPENDIX TABLE III.

Positive and negative comments and suggested changes for the larger study.

ID	Positive Comments	Negative Comments	Training suggested
1	Enjoyed feeling that the study physician was his advocate and helping adjust medications promptly. "I liked being aware of my BP every day. Measuring BP became a habit."		
2	I like that the reading are sent automatically. I like keeping an eye on my BP and getting into the habit of measuring BP. I am motivated to measure my BP daily and I know my BP will climb up if I miss my medication. When I was not in the trial, this feedback was not there.		
3	Study made me aware of my BP. The study was slick once it worked. Taking my BP daily is a habit now. Once it worked it was easy.		Need more training on how to use an iphone. I would have liked refresher training.
4	Liked the slick smart phone. Like the feedback from the system.	May not have time to do this daily.	
7	This is the best thing that happened to me. Made me aware of my BP. Appreciated medical care and watchfulness. This became a ritual. I wanted to use it several times / day. If I was not in the study, my BP would be high and I would fall through the cracks.		
8	Being monitored gave me peace of mind after my hypertensive stroke. Helped me be aware.		
9	The training was very thorough. I liked that it let me know my readings. And that it sent BP to MD and that the MD would know my readings immediately I am quite impressed with how thorough the study was.		
10	It brought to light that my BP was high. I was worried about the stroke and how I was going to manage. I did not even know about BP. It was interesting to know that my BP was really high in the morning but OK at lunch. I liked knowing my BP and talking to Sarah every week (PharmD co-I). I liked that someone else had control of the readings and I do not have to push buttons. It went right through. The study was very simple and very thorough.	I did not like having to do it every morning. But I will do it several times / week – just not every day like the study.	
14	I knew the app. Simple instructions. Helpful to do every day. Got in a routine. Otherwise, I have to go to clinic or drug store to get a BP reading. This made me aware of my condition every day. Helped me not to forget my		

ID	Positive Comments	Negative Comments	Training suggested
	medication. Was quite an education. I liked that the BP uploaded directly to the doctor. Information sent directly to the doctor. MD can then manage. Easy to understand. I will use home BP monitoring in the future – not only for me but my wife too. She has BP problems. Before we were going to the drug store. The doctor was on top of my BP. I liked that she could change my meds if needed. Otherwise, I would have to go to the clinic. Size is nice. Small and compact.		
15	It was easy, quick, took 5 minutes at the most. Study let me know about my BP goals.		Would have liked more phone training.
16	The training when the coordinator came to my home was more useful. I was out of it in the hospital. It was easy to use the equipment. The system let me know when my BP was getting high.		
17	This put me on the spot and made me accountable. The system was straightforward and easy to use. The system lets me take BP as many times as I wanted to. I took my BP often to make sure that it was going okay. I like the ease. I like that the information is going to the MD. That is neat! I cannot emphasize that enough.		
18	It helped me keep track of my BP. I also wrote down the BP from my study and brought it to my primary care MD. He really liked that. The study MD made medication changes. I did not know her that well. I asked my primary care provider. He agreed with the changes made by study MD. I liked that the BP was transmitted automatically.	Kind of confusing in the beginning.	Would like more written step by step instructions.
19	The training gave me confidence that the readings were correct. Convenient. More comfortable at home. Simple. I like that BP is being sent to someone who monitors the BP.	I don't like taking BP every day.	
21	Overall this was helpful as the medication adjustment helped stabilize BP. Simple and easy to use. Liked that it was automatic.	Somewhat anxiety provoking to measure BP every day. Would it be high or low? If the readings were different – was it me or the machine?	Need written instruction about what arm to use.
23	Easy. Not complicated. Learned the importance of taking BP more than once to get accurate reading. It was convenient and easy to use.		Should have provided training on changing batteries.
24	Once I had the system working, I could do it in less than a minute.	Felt that machine BP was high because it was higher than what was measured during his hospital stay particularly during rehabilitation.	Not familiar with Apple.
25	My BP problems are tied to diet. When I saw my BP spike during trial, it was reminder to eat better. Simple straightforward not complicated.		
27	System was simple. It told me how my BP was. Especially since I was on medication it was helpful to me. Automatic transmission was convenient.		
33	I did not have any problems with machine. I liked keeping track on a regular basis. I never did before. I liked that I did not have to call it in (automatic transmission).	I did not like doing it every day.	
34	Learned something about my BP in the morning. I like knowing my BP readings. This was similar to my own monitor. I like that it was automatic.	I don't like doing it in the morning.	Need a repeat demonstration of system.

ID	Positive Comments	Negative Comments	Training suggested
36	Gave me confidence. We detected the low BP as well. Easiest device ever used. We could get multiple measurements on the same device. It was simple.		Instructions on going back to main screen.
38	Helped me know when I was having AFIB. Helped adjust my medications. I often had high readings and they had to adjust.		
40	Liked that it was automatic.	Interested for 2 months.	Provide confirmation that BP uploaded to study database. More written instructions.
41	Nice and easy. Like that it sent readings automatically.		Would like training on changing batteries on cuff beforehand

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Figure1.
CONSORT Participant Flow Diagram.

Figure 2.

Trajectory of systolic and diastolic blood pressures (SBP, DBP) of a participant in the intervention arm. Seven-day moving averages of blood pressures are shown since medication adjustment was based on 7-day blood pressure readings.

Table 1.

Demographics and Baseline Characteristics of Participants Who Completed the Study and Those Who Withdrew.

	Intervention N=26	Control N=24	Withdrawn (from Intervention) N=6
Mean Age in years, (SD, range)	63.1 (9.7, 42–81)	68.3 (10.0, 46–85)	60.33 (13.7, 47–84)
Female Sex N (%)	6 (23.1)	8 (32.0)	4 (66.7)
White Race, N (%)	24 (92.3)	21 (87.5)	6 (100.0)
Marital Status, N (%)			
Married	19 (73.1)	17 (70.8)	4 (66.7)
Single	5 (19.2)	7 (29.2)	2 (33.3)
Other/Unknown	2 (7.7)	0 (0.0)	0 (0.0)
Education N (%)			
High School or less	4 (15.4)	7 (29.2)	0 (0.0)
Some College	8 (30.8)	9 (37.5)	4 (66.7)
College	8 (30.8)	5 (20.8)	2 (33.3)
Graduate School	4 (15.4)	3 (12.5)	0 (0.0)
Other	2 (7.7)	0 (0.0)	0 (0.0)
Modified Rankin Score, Median (IQR)	1.5 (0,3)	2 (1,3)	2.0 (1, 3)

Table 2.

Feasibility. Participants transmitted their BP on average 89% of the days under monitoring and 92% of participants transmitted their BP for more than half the monitored days.

Total N = 26	Days Transmitted	Participants N (%)
90 day monitoring <u>N = 19</u>	80–90	12 (63)
	70–79 *	3 (16)
	60–69	1 (5)
	50–59	1 (5)
	< 50	2 (11)
Extended monitoring <u>N=7</u>	Transmitted daily until HTN controlled or it was felt that control could not be achieved and participant was referred back into primary care	5 (71)
	Monitored for 103, 107 **, 113, 115, 121 days	2 (29)
	Transmitted 91 of 101 monitored days	
	Transmitted 173 of 177 days ***	

A total of 3 intervention participants did not meet the primary outcome of BP control as described below.

* Had technical difficulties measuring BP.

** Was resistant to BP medication addition.

*** Had fluctuating BP and was referred back to primary care for ambulatory monitoring.

Table 3.

Results of the Marshfield Usability Survey: (1=Strongly Disagree; 2=Disagree; 3= Neither Agree nor Disagree; 4=Agree; 5=Strongly Agree). Results indicate very high usability. N = 25. SD = standard deviation, IQR = interquartile range.

Marshfield usability survey statements	Mean (SD)	Median(IQR)
I thought the system was easy to use	4.6 (0.5)	5 (4.0–5.0)
I felt very confident using the system	4.5 (0.5)	5 (4.0–5.0)
I needed to learn a lot of things before I could get going with the system	2.1 (1.0)	2 (1.0–2.0)
I felt that I needed someone's help to be able to use the system	2.3 (1.3)	2 (1.0–4.0)
I found the system to be complex	1.6 (0.5)	2 (1.0–2.0)
Using the system did not take much time	4.5 (0.5)	5 (4.0–5.0)
I could always trust the system to work	4.1 (0.9)	4 (4.0–5.0)
My privacy was protected when I used the system	4.2 (0.8)	4 (4.0–5.0)
Using the system was as satisfying as talking to a real person	3.7 (0.8)	4 (3.0–4.0)
It was easy to learn to use the system	4.5 (0.6)	5 (4.0–5.0)
In general, I was satisfied with the system	4.6 (0.5)	5 (4.0–5.0)
I think most people could learn to use the system very quickly	4.4 (0.7)	5 (4.0–5.0)
I think I would like to use the system again	3.8 (1.1)	4 (3.0–5.0)
The system could help me better manage my health and medical needs	4.1 (1.1)	4 (4.0–5.0)
I could be more involved in my care by using the system	4.1 (1.1)	4 (4.0–5.0)
The system could help me monitor my medical condition	4.1 (1.0)	4 (4.0–5.0)

Table 4.

Efficacy of HTN control Intervention Arm (IA) vs. Control Arm (CA)

N	INTERVENTION	CONTROL	p-value
Randomized	34	22	
Withdrawn (data not used)	6	0	
Intent to Treat for Primary Outcome	28	22	
Crossed Over From Intervention to Control	2		
As Treated Total for Primary Outcome	26	24	
INTENT TO TREAT ANALYSIS			
Study Start and End BP reported on N	28	22	
SBP < 140 mm Hg at enrollment (goal)	14 (50%)	11(50%)	
SBP < 140 mm Hg at study end (goal)	23 (82%)	14(64%)	IA:P=0.0077 CA::p=0.51 *
Average SBP Study Start	140.0 (15.7)	139.8 (16.3)	
Average SBP Study End	130.2 (11.4)	133.9 (16.9)	IA:p=0.005 ** CA: p=0.115
AS TREATED ANALYSIS			
Study Start and End Blood Pressure data reported on N	26	24	
SBP < 140 mm Hg at enrollment (goal)	14 (54%)	11(46%)	
SBP < 140 mm Hg at study end (goal)	23 (89%)	14(58%)	IA:P=0.0077 CA::p=0.51 *
Average SBP Study Start	139.7 (16.2)	140.2 (15.7)	
Average SBP Study End	128.8 (10.5)	135.1 (16.7)	IA: p=0.0036 ** CA: p=0.1403

* The McNemar test was similar for the intent to treat and as treated analysis and was significant for the intervention arm (chi-square=7.11, p=0.0077) but not for the control arm, (chisquare=0.44, p=0.51).

** Intent to treat: Paired T-test Control Arm (CA). Mean difference pre vs. post = 5.91 (95% CI: -1.57,13.38), p=0.115. Intervention Arm (IA). Mean difference pre vs. post = 9.88 (95% CI: 3.17, 16.40), p=0.005. Two-sample t-test comparing mean changes in between groups was not significant, (p=0.4).

** As treated: Paired T-Test CA. Mean difference pre vs. post = 5.13 (95% CI: -1.82, 12.07), p=0.1403. IA Mean difference pre vs. post = 10.81 (95% CI: 3.86, 17.76), p=0.0036. Two sample t-test comparing mean changes between groups was not significant, (p=0.2).